The Effect of Residential Property Redevelopment on Urban Forest Dynamics in Christchurch, New Zealand

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Dedicated to the memory of my beloved father

Zhanhong Guo (1964-2011)

You are gone but your belief in me has made this journey possible!

Table of Contents

List of Figures v

List of Tables vii

Abstract v

Acknowledgements xiii

Chapter 1 Introduction 1

1.1 Background 1

1.2 Literature Review 2

1.2.1 Definition of Key Terms 2

1.2.2 Urban Forest Ecosystem Services 5

1.2.3 Urban Forest Dynamics during Urban Renewal and Redevelopment 7

1.2.4 Potential Factors Affecting Urban Forest Dynamics 8

1.3 Knowledge Gap 12

1.4 Research Problem 13

1.5 Thesis Organisation 14

Chapter 2 The Effects of Property Redevelopment on Urban Tree Canopy Cover Change 15

2.1 Introduction 15

2.2 Methods 16

2.2.1 Study Area 16

2.2.2 Remote Sensing Data Acquisition 17

2.2.3 Tree Canopy Mapping 18

2.2.4 Accuracy Assessment 21

2.2.5 Residential Property Redevelopment 21

2.2.6 Statistical Analysis 22

2.3 Results 23

2.3.1 Classification Accuracy Assessment 23

2.3.2 Tree Canopy Cover Change 23

2.3.3 Effects of Redevelopment on Tree Canopy Cover Change 24

2.4 Discussion 24

2.5 Conclusion 28

Chapter 3 The Effects of Property Redevelopment on Property-scale Tree Removal and Retention 29

3.1 Introduction 29

3.2 Methods 30

3.2.1 Study Area 30

3.2.2 Data and Analysis 33

3.3 Results 39

3.3.1 Model Performance 39

3.3.2 Variable Importance 40

3.4 Discussion 42

3.4.1 Variable Importance in Predicting Tree Removal and Retention 42

3.4.2 Tree and Property-scale versus Broader-scale Explanatory Variables 45

3.4.3 Canopy Cover versus Individual Tree Dynamics 46

3.4.4 Management Implications 46

3.5 Conclusion 47

Chapter 4 The Effects of Property Redevelopment on Resident Attitudes and Actions towards Trees 49

4.1 Introduction 49

4.2 Methods 51

4.2.1 Study Area 51

4.2.2 Questionnaire 52

4.2.3 Statistical Analysis 54

4.3 Results 54

4.3.1 Tree Management Actions 56

4.3.2 Resident Attitudes towards Tree Removal, Retention, and Planting 56

4.4 Discussion 60

4.4.1 Reasons for Tree Management Actions 61

4.4.2 Management Implications 63

4.4.3 Limitations of the Study 64

4.5 Conclusion 65

Chapter 5 Conclusion 67

5.1 Summary of Main Findings 67

5.1.1 City- and Meshblock-scale Tree Canopy Cover Change 67

5.1.2 Property-scale Individual Tree Dynamics 68

5.1.3 Resident Attitude and Actions towards Trees 69

5.2 Research Implications 69

5.3 Limitations and Future Research 70

5.4 Conclusion 72

References 74

Appendices **94**

Appendix A. Feature inclusion for object-based image analysis 94

Appendix B. Tree canopy cover change including plantation forests 95

Appendix C. Questionnaire Sample 96

Appendix D. A residential property was identified as a redeveloped property after visual comparison between 2011 and 2015/16 aerial photographs. 100

List of Figures

Figure 1.1 – A conceptual framework of urbanisation. 4

Figure 2.1 – Location of redeveloped properties in Christchurch, New Zealand, as well as, the boundaries for meshblocks and the study area. 17

Figure 2.2 – Comparison between 2011 and 2015 input remote sensing datasets for tree canopy mapping. 19

Figure 2.3 – Tree canopy cover change and tree canopy cover in 2011 and 2015. 25

Figure 2.4 – Misclassifications of tree canopy. 27

Figure 3.1 – Dots show individual residential properties included in the study. 31

Figure 3.2 – Trees present in the 2011 and 2015/16 aerial photograph on a redeveloped residential property. 37

Figure 3.3 – The classification tree for the model with the highest overall accuracy (ESL model). 41

Figure 4.1 – Distribution of individual residential properties included in the study. 52

List of Tables

Table 1.1 – Summary of definitions of urban greenspace, urban forest, and urban tree from selected studies. 3

Table 1.2 – Definitions of terms related to urban renewal. 5

Table 1.3 – Urban forest ecosystem services. 6

Table 2.1 – Summary of remote sensing data resources used in this study. 18

Table 2.2 – Optimal parameter values for conducting multi-resolution segmentation. 20

Table 2.3 – Confusion matrix for 2011 and 2015 classification accuracy assessment. 23

Table 2.4 – Summary statistics for tree canopy cover and tree canopy cover change on redeveloped versus non-redeveloped meshblocks. 24

Table 3.1 – Summary of remote sensing data resources acquisition. 32

Table 3.2 – Summary of candidate explanatory variables included in the classification tree analysis (n = 450). 34

Table 3.3 – Summary of models for predicting whether trees were removed or retained. 38

Table 3.4 – Summary statistics for retained and removed trees on redeveloped and non-redeveloped residential properties. 39

Table 3.5 – Results of model validation. 40

Table 3.6 – Summary of the complete classification tree of model ESL. 43

Table 4.1 – Explanation of tree management actions in questionnaire. 53

Table 4.2 – Socio-demographic characteristics of respondents and their property status based on questionnaires (n = 445). 55

Table 4.3 – Summary of tree management actions after 2010 – 2011 CES. 56

Table 4.4 – The reasons provided by landowners for removing trees on their property (n = 356). 57

Table 4.5 – The reasons provided by landowners for retaining trees on their property (n = 392). 59

Table 4.6 – The reasons provided by landowners for planting trees on their property (n = 301). 60

Abstract

As a global phenomenon, many cities are undergoing urban renewal to accommodate rapid growth in urban population. However, urban renewal can struggle to balance social, economic, and environmental outcomes, whereby economic outcomes are often primarily considered by developers. This has important implications for urban forests, which have previously been shown to be negatively affected by development activities. Urban forests serve the purpose of providing ecosystem services and thus are beneficial to human wellbeing. Better understanding the effect of urban renewal on city trees may help improve urban forest outcomes via effective management and policy strategies, thereby maximising ecosystem service provision and human wellbeing. Though the relationship between certain aspects of development and urban forests has received consideration in previous literature, little research has focused on how the complete property redevelopment cycle affects urban forest dynamics over time. This research provides an opportunity to gain a comprehensive understanding of the effect of residential property redevelopment on urban forest dynamics, at a range of spatial scales, in Christchurch, New Zealand following a series of major earthquakes which occurred in 2010 – 2011. One consequence of the earthquakes is the redevelopment of thousands of properties over a relatively short time-frame. The research quantifies changes in canopy cover city-wide, as well as, tree removal, retention, and planting on individual residential properties. Moreover, the research identifies the underlying reasons for these dynamics, by exploring the roles of socio-economic and demographic factors, the spatial relationships between trees and other infrastructure, and finally, the attitudes of residential property owners.

To quantify the effect of property redevelopment on canopy cover change in Christchurch, this research delineated tree canopy cover city-wide in 2011 and again in 2015. An object-based image analysis (OBIA) technique was applied to aerial imagery and LiDAR data acquired at both time steps, in order to estimate city-wide canopy cover for 2011 and 2015. Changes in tree canopy cover between 2011 and 2015 were then spatially quantified. Tree canopy cover change was also calculated for all meshblocks (a relatively fine-scale geographic boundary) in Christchurch. The results show a relatively small magnitude of tree canopy cover loss, city-wide, from 10.8% to 10.3% between 2011 and 2015, but a statistically significant change in mean tree canopy cover across all the meshblocks. Tree canopy cover losses were more likely to occur in meshblocks containing properties that underwent a complete redevelopment cycle, but the loss was insensitive to the density of redevelopment within meshblocks.

To explore property-scale individual tree dynamics, a mixed-methods approach was used, combining questionnaire data and remote sensing analysis. A mail-based questionnaire was delivered to residential

properties to collect resident and household data; 450 residential properties (321 redeveloped, 129 non-redeveloped) returned valid questionnaires and were identified as analysis subjects. Subsequently, 2,422 tree removals and 4,544 tree retentions were identified within the 450 properties; this was done by manually delineating individual tree crowns, based on aerial imagery and LiDAR data, and visually comparing the presence or absence of these trees between 2011 and 2015. The tree removal rate on redeveloped properties (44.0%) was over three times greater than on non-redeveloped properties (13.5%) and the average canopy cover loss on redeveloped properties (52.2%) was significantly greater than on non-redeveloped properties (18.8%).

A classification tree (CT) analysis was used to model individual tree dynamics (i.e. tree removal, tree retention) and candidate explanatory variables (i.e. resident and household, economic, land cover, and spatial variables). The results indicate that the model including land cover, spatial, and economic variables had the best predicting ability for individual tree dynamics (accuracy = 73.4%). Relatively small trees were more likely to be removed, while trees with large crowns were more likely to be retained. Trees were most likely to be removed from redeveloped properties with capital values lower than NZ$1,060,000 if they were within 1.4 m of the boundary of a redeveloped building. Conversely, trees were most likely to be retained if they were on a property that was not redeveloped. The analysis suggested that the resident and household factors included as potential explanatory variables did not influence tree removal or retention.

To conduct a further exploration of the relationship between resident attitudes and actions towards trees on redeveloped versus non-redeveloped properties, this research also asked the landowners from the 450 properties that returned mail questionnaires to indicate their attitudes towards tree management (i.e. tree removal, tree retention, and tree planting) on their properties. The results show that residents from redeveloped properties were more likely to remove and/or plant trees, while residents from non-redeveloped properties were more likely to retain existing trees. A principal component analysis (PCA) was used to explore resident attitudes towards tree management. The results of the PCA show that residents identified ecosystem disservices (e.g. leaf litter, root damage to infrastructure) as common reasons for tree removal; however, they also noted ecosystem services as important reasons for both tree planting and tree retention on their properties. Moreover, the reasons for tree removal and tree planting varied based on whether residents' property had been redeveloped. Most tree removal occurred on redeveloped properties because trees were in conflict with redevelopment, but occurred on non-redeveloped properties because of perceived poor tree health. Residents from redeveloped properties were more likely to plant trees due to being aesthetically pleasing or to replace trees removed during redevelopment.

Overall, this research adds to, and complements, the existing literature on the effects of residential property redevelopment on urban forest dynamics. The findings of this research provide empirical support for developing specific legislation or policies about urban forest management during residential property redevelopment. The results also imply that urban foresters should enhance public education on the ecosystem services provided by urban forests and thus minimise the potential for tree removal when undertaking property redevelopment.

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Chapter 1

Introduction

1.1 Background

According to the most recent data from the United Nations, the world's urban population reached 58 percent in 2018 and is expected to rise to 68 percent by 2050 (UN DESA, 2018). To accommodate growing urban populations, planners and developers have expanded urban boundaries, occupied more edge-of-city and rural land, and built more public infrastructure and buildings for industrial, commercial, and housing uses (Haaland & Konijnendijk, 2015; Simson, 2008). Many of these activities can be considered as urban sprawl which, some have argued, should be restricted because land resources are finite (Gennaio, Hersperger, & Bürgi, 2009; Gong, Chen, Liu, & Wang, 2014; Jiang, Deng, & Seto, 2013). In contrast, urban renewal can be considered as a way to address the urbanisation associated with increasing urban populations (Chen & Lai, 2013; Smith, Clayden, & Dunnett, 2009).

Urban renewal is based on morphologically redeveloping cities, converting obsolete industrial areas and improving existing urban forms instead of extending urban fringes outward. Thus, urban renewal alleviates some of the undesirable effects of urbanisation, such as conversion of rural land to urban land (Berland, 2012; Hauser & Schnore, 1965). Despite considering manifold advantages of urban renewal (Ki & Jayantha, 2010; Paull, 2008; Uduku, 1999), undesirable consequences of certain aspects have been caused by uncoordinated and unreasonable developments (Melia, Parkhurst, & Barton, 2011; Neuman, 2005; Norrman et al., 2016). When undertaking urban renewal, it is paramount but difficult to balance social, economic and environmental outcomes and ensure the sustainability of urban development, especially without sufficient theoretical and technical knowledge (Bailey & Nsokimieno, 2016). As such, economic interests are often prioritised over social or environmental interests (Hofstad, 2012).

From a social perspective, urban renewal may have impacts on social justice. While social dissatisfaction due to crowded residential environments, narrow roads, and deficient privacy has been generally argued as a consequence of intensification and infill development (Byrne, Sipe, & Searle, 2010; Conway, 2009; Ellis, 2002; Jim & Liu, 2001), some studies have also highlighted the positive outcomes of higher density areas, such as providing a pedestrian-friendly environment and encouraging social interaction (Leyden, 2003; Toit, Cerin, Leslie, & Owen, 2007). With respect to environmental justice, previous research has found that urban renewal can have negative impacts on ecosystem services

(Cavan et al., 2014; Tian, Jim, & Wang, 2014). This is especially true when it comes to urban forests that provide ecosystem services (Dobbs, Escobedo, & Zipperer, 2011; Jim & Chen, 2008). Amongst the many reasons to conserve existing, or create new urban forests when undertaking urban renewal, human well-being and health are paramount (Coutts & Hahn, 2015; Ekkel & de Vries, 2017). It is therefore meaningful to understand how urban forests have been affected by urban renewal and thus provide feasible management strategies to maximise urban forest outcomes and related ecosystem services.

1.2 Literature Review

This section reviews previous studies on urban forests during urban development, and provides the theoretical and methodological foundation for this thesis. Specifically, the review begins by defining urban forests and different types of urban renewal, and then introduces urban forest ecosystem services. Subsequently, the review assesses urban forest dynamics during urban renewal and identifies how urban morphological and human factors influence urban forests and urban trees.

1.2.1 Definition of Key Terms

1.2.1.1 Urban Greenspace, Forests and Trees

Previous research on urban forests has attempted to define the terms urban greenspace and urban forest (Table 1.1). Rather than redefine these terms, this review follows the definitions of previous studies. Specifically, this review describes urban greenspace as the aggregation of all vegetated areas including trees, shrubs, lawns, and flowers that are located in built-up areas (Lo & Jim, 2012), while urban forest is considered as a subset of urban greenspace and is defined as the sum of all the natural and planted trees in urban areas (Ordóñez & Duinker, 2010). For the term urban tree, while few studies have provided an actual definition (Roy, Byrne, & Pickering, 2012), this review follows the definition of Vesely (2007) who defines urban trees as "…those trees which are present in cities on residential, industrial and commercial properties, in parks, reserves and botanic gardens, on crown land, golf courses, school grounds and streets".

Within a city, urban forest consists of trees located in publicly and privately managed land. This review differentiates those trees on their tenure and management responsibilities. Public urban trees are defined as those trees located in public land (e.g. parks and roads) and thus are managed by government authorities. Private urban trees are those trees that are planted on private property and maintained exclusively by private landowners.

Table 1.1 – Summary of definitions of urban greenspace, urban forest, and urban tree from selected studies.

Term	Definition	Reference
Urban greenspace	"…urban green spaces − that is forests, trees, parks, allotments or cemeteries − provide a whole range of ecosystem services for the residents of a city."	Bastian, Haase, and Grunewald (2012)
	"…unsealed, permeable and soft surfaces such as soil, grass, shrubs, trees and water."	James et al. (2009)
	"…broadly encompass publicly accessible areas with natural vegetation, such as grass, plants or trees [and may include] built environment features, such as urban parks, as well as less managed areas, including woodland and nature reserves."	Lachowycz and Jones (2013)
	"…vegetated areas located within built-up areas, including natural and planted trees, grass, shrubs and flowers."	Lo and Jim (2012)
Urban forest	"…the tree and soil components of an urban ecosystem and are characterized by their structure, amount (e.g. volume), size (e.g. height and diameter), distribution (e.g. covers), and composition (e.g. number of species, soil types)."	Dobbs et al. (2011)
	"…the sum of all urban trees, shrubs, lawns, and pervious soils located in highly altered and extremely complex ecosystems where humans are the main drivers of their types, amounts, and distribution."	Escobedo, Kroeger, and Wagner (2011)
	"…forest patches located within, or continuous forest cover on the fringe of, urban agglomerations, intensively used for recreation."	Gundersen, Frivold, Myking, and Øyen (2006); Rydberg and Falck (1998)
	"Urban forestry is the management of planted and naturally occurring trees in urban and urban-interface areas."	Harris, Clark, and Matheny (2004)
	"…the sum of all woody and associated vegetation in and around dense human settlements, ranging from small communities in rural settings to metropolitan areas."	Miller (2007)
	"Urban forests can be broadly defined as the natural and planted trees in urban areas."	Ordóñez and Duinker (2010)
	"…the trees and vegetation in the cities, towns, and communities where people live and work."	Vogt, Fischer, and Hauer (2016)
Urban tree	"…an urban tree is a woody perennial plant growing in towns and cities, typically having a single stem or trunk − and usually a distinct crown − growing to a considerable height, and bearing lateral branches at some height from the ground."	Roy et al. (2012)
	"…those trees which are present in cities on residential, industrial and commercial properties, in parks, reserves and botanic gardens, on crown land, golf courses, school grounds and streets."	Vesely (2007)

1.2.1.2 Urban Renewal and Urban Redevelopment

Previous research has employed terms including urban renewal, urban regeneration, urban redevelopment, urban revitalisation, new urbanism, consolidation, densification, intensification, and infill development to describe post-urbanisation development (Table 1.2). These terms share similar meanings but can differ considerably in certain aspects. Zheng, Shen, and Wang (2014) reviewed previous studies on post-urbanisation development and categorised different terms based on research scale. They sort urban renewal and urban regeneration as a group at a large scale and sort urban redevelopment and urban revitalisation as a group at a small scale. New urbanism has a similar meaning to urban renewal and urban regeneration but focuses on human-scaled urban morphologies. This review uses the term urban renewal at a citywide scale and the term urban redevelopment at a neighbourhood or property scale. With respect to the subsets of redevelopment (Figure 1.1), intensification, densification, and urban consolidation share a similar goal of restricting urban sprawl (Burton, Jenks, & Williams, 2003). Although both infill development and intensification (densification; consolidation) emphasise an increase in density of population and buildings, there is a subtle difference between these two terms. Infill development focuses on new townhouses or houses that are constructed on existing residential areas, while intensification focuses on increasing building density through converting industrial or commercial buildings into large apartment buildings that generally are over three storeys (Sharpin, 2006).

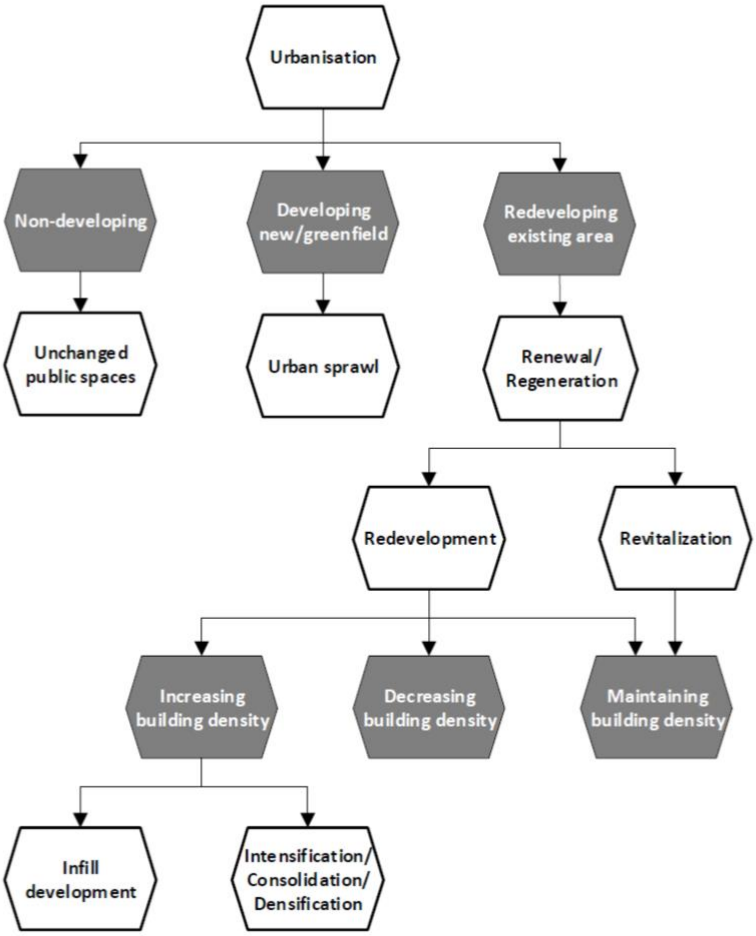

Figure 1.1 – A conceptual framework of urbanisation. Grey polygons show urban development processes; white polygons show the types of urban development.

Table 1.2 – Definitions of terms related to urban renewal.

Term	Definition	Reference
Urbanisation	"…involves an array of interrelated processes—cultural, economic, demographic, political, social, and technological—that transforms the regional or national landscape into one where more and more people live in large towns and cities."	Knox and McCarthy (1994) cited by Mulligan (2013)
Urban sprawl	"…a phenomenon is of interest because of the high level of automobile usage, segregated land uses, disparities in fiscal capacities of local governments, and development that alternates relatively low-density land uses and undeveloped land in a rather haphazard fashion."	Johnson (2001)
Urban renewal	"…a process involving clearance of slum or blight areas, urban redevelopment, urban revitalisation, building rehabilitation, preservation and conservation to improve urban fabric, and meet certain economic, environmental and social objectives."	Chan and Lee (2008)
Urban regeneration	"…a comprehensive and integrated vision and action to resolve the multi-faceted problems of urban areas and to improve the economic, physical, social and environmental conditions of deprived areas."	Ercan (2011)
New urbanism	"…integrates traditional urban morphological characteristics to be compact and create vibrant, pedestrian-friendly communities that have a relatively low environmental impact."	Congress for the New Urbanism (2000) cited by Conway (2009)
Urban redevelopment	"…being any new construction on a site that has pre-existing uses, such as the redevelopment of a block of townhouses into a large apartment building."	De Sousa (2008) cited by Zheng et al. (2014)
Urban revitalisation	"…a restoring a building to good condition, operation, or capacity."	Zuckerman (1991) cited by Zheng et al. (2014)
Urban consolidation	"…a planning strategy of increasing housing density in established urban areas by utilizing existing infrastructure and amenities while restricting urban sprawl."	McCrea and Walters (2012)
Intensification	"…taking the existing urban form – whatever that is – and makes it more dense, with more people and dwellings on the same area."	Minnery (1992) cited by Williams (1999)
Densification	"…the construction of new housing units within existing residential areas."	Broitman and Koomen (2015)
Infill development	"…the establishment of new dwellings within an existing suburb, facilitated by the division of existing residential properties into smaller sections by way of cross-leasing, or subdivision into fee-simple or unit titles."	Sharpin (2006)

1.2.2 Urban Forest Ecosystem Services

Urban forests produce a variety of ecosystem services (Bolund & Hunhammar, 1999). Trees in cities play a vital role in sequestering carbon (Nowak, Greenfield, Hoehn, & Lapoint, 2013a), reducing air pollution (Jim & Chen, 2008), moderating the urban heat island effect (Tan, Lau, & Ng, 2016), and reducing storm-water runoff (Berland et al., 2017). Other than maintaining the sustainable development of a city (Capotorti, Mollo, Zavattero, Anzellotti, & Celesti-Grapow, 2015; Duinker et al., 2015; Zhu

& Zhang, 2008), urban trees can also be beneficial to people by providing food and wood products (MacFarlane, 2009; McLain, Poe, Hurley, Lecompte-Mastenbrook, & Emery, 2012), improving well-being (Hansmann, Hug, & Seeland, 2007), increasing property values (Wolf, 2007), and reducing costs of heating or cooling (McPherson & Rowntree, 1993; McPherson & Simpson, 2003). These diverse ecosystem services can be classified as provisioning services, regulating services, cultural services, and supporting services (Table 1.3). However, ecosystem service provision is moderated by canopy cover (Dobbs et al., 2011) and tree structure (Nowak, Hoehn, Bodine, Greenfield, & O'Neil-Dunne, 2013b). Thus, to maximise ecosystem services, urban planning and development must be undertaken in ways that minimises their negative impact on urban forests.

Table 1.3 – Urban forest ecosystem services.

Category	**Example/Description**		**Reference**
Provisioning services	Food	providing edible products	Hurley and Emery (2018); McLain et al. (2012)
Provisioning services	Timber	providing timber and building materials	Kaoma and Shackleton (2014); Stocchero, Seadon, Falshaw, and Edwards (2017)
Provisioning services	Fuel production	providing bio-based fuels for power and heat generation	Cardoso, Ladio, and Lozada (2013); MacFarlane (2009)
Regulating services	Carbon sequestration	storing and sequestering substantial amounts of carbon	Nowak et al. (2013a)
Regulating services	Climate regulation	regulating urban microclimate patterns; decreasing the temperature of urban surface	Lin, Meyers, Beaty, and Barnett (2016); Tan, Lau, and Ng (2017)
Regulating services	Air purification	reducing air pollution	Escobedo and Nowak (2009); Grote et al. (2016)
Cultural services	Recreation	providing places for recreational activities	Hörnsten and Fredman (2000); Koo, Park, and Youn (2013)
Cultural services	Human wellbeing	Improving human mental and physical health	Dallimer et al. (2012)
Cultural services	Aesthetic	beautifying streets, commercial districts, and communities with trees and shrubs; decorating open space or water surface	Roy et al. (2012); Sander, Polasky, and Haight (2010); Tyrväinen, Silvennoinen, and Kolehmainen (2003)
Supporting services	Habitat maintenance	offering sufficient habitat for wildlife; enriching urban biodiversity	Lerman et al. (2014); MacGregor-Fors et al. (2016); Stagoll, Lindenmayer, Knight, Fischer, and Manning (2012)
Supporting services	Storm-water runoff	soil protection	Berland et al. (2017); Kirnbauer, Baetz, and Kenney (2013)

1.2.3 Urban Forest Dynamics during Urban Renewal and Redevelopment

Urban greenspace, incorporating trees, shrubs, and grass, provides opportunities for residents to access nature. However, the structure, composition and extent of these natural amenities are temporally dynamic, and are impacted by urban renewal and redevelopment. Dallimer et al. (2011) reported the extent of urban greenspace observed a net increase in England prior to 2001 but subsequently reduced due to implementing a densification policy. Specifically, one English town, Merseyside, lost 5% urban greenspace coverage due to infill development (Pauleit, Ennos, & Golding, 2005). In Como, Western Australia, urban trees were often completely removed after the government implemented urban renewal to improve neighbourhoods (Brunner & Cozens, 2013). Other studies on the correlation between urban forests and urban renewal in Hong Kong (Jim, 1998), Toronto (Steenberg, Millward, Duinker, Nowak, & Robinson, 2015), Baltimore (Merse, Buckley, & Boone, 2009), and Sheffield (Davies et al., 2008) generally show the negative impact of renewal on urban greenspace or trees.

Many studies have explored this relationship by monitoring changes in canopy cover at broad scales, associated with different forms of development (Hostetler, Rogan, Martin, Delauer, & O'Neil-Dunne, 2013; Nowak & Greenfield, 2012). In contrast, some recent studies have highlighted fine-scale tree loss dynamics. Cities are agglomerations of private and public landowners; a consequence of this fractured land ownership is that urban forest dynamics are influenced by landowners in a city. At this fine scale, the impacts of tree loss are especially manifest when trees are exposed to construction and demolition activities (Koeser, Hauer, Norris, & Krouse, 2013; Morgenroth, O'Neil-Dunne, & Apiolaza, 2017); this is a fine-scale reflection of the oft-reported large-scale relationship between tree canopy cover and development (Nowak & Greenfield, 2018). However, few studies, with the exception of Lee, Longcore, Rich, and Wilson (2017), have considered the role of the complete redevelopment cycle on fine-scale tree dynamics. Lee et al. (2017) found redevelopment of detached single-unit houses led to tree cover loss, but they did not explore property-level factors associated with tree loss likelihood when redevelopment occurs.

During the process of development and renewal of urban areas, the urban forest can experience change that can have positive, neutral, or negative implications. Tree canopy cover loss can be offset through sustainable urban planning (Elmes et al., 2018; Kaspar, Kendal, Sore, & Livesley, 2017). Achieving urban forest preservation and creation can be used to assess a successful redevelopment of brownfield (Rashid & Ara, 2015; Silverthorne, 2006). Previous research suggests that redeveloping reclaimed brownfield sites can indeed serve a purpose to increase urban forest cover after improving soil quality and creating habitat (Ashwood, Doick, Atkinson, & Chenoweth, 2014; Mathey, Rößler, Banse, Lehmann, & Bräuer, 2015). With respect to novel approaches to urban forest inclusion in new developments, rooftop and vertical green infrastructure can make a direct contribution to increased urban forest cover (Getter & Rowe, 2006). These green infrastructural elements not only serve as a way for building energy savings (Wong, Tay, Wong, Ong, & Sia, 2003), but also provide people living in compact cities access to natural amenities.

From a temporal perspective, a study conducted in Minnesota's Twin Cities Metropolitan Area showed that urban tree canopy cover tends to decrease when urbanisation initially occurs, but increases over time (Berland, 2012). This provides insights that it may take decades for trees to mature and contribute meaningfully to urban forest cover (Brunner & Cozens, 2013). Clearly, it is necessary to consider temporal lags in urban forest dynamics when assessing the effects of urbanisation in its many forms.

1.2.4 Potential Factors Affecting Urban Forest Dynamics

1.2.4.1 Urban Morphology

Urban redevelopment causes changes to urban form, performed by neighbourhood improvements through replacing or modifying neighbourhood morphological features (Ellis, 2002; Thompson-Fawcett & Bond, 2003). Neighbourhoods comprise roads, sidewalks, buildings, and urban forests, with each feature playing an important role and interacting with other features. Roads serve an influential function of dividing and connecting a spatial grouping of buildings; urban forests, mosaicked in neighbourhoods surrounded by roads and buildings, are vulnerable to changes to other features.

Road-related developments mainly affect roadside trees. As a key consequence of urban redevelopment, high road density and narrow road width facilitate convenience in human daily life through increased connectivity (Conway, 2009). But, changes to road patterns are likely to cause conflicts with natural ecosystems (Gordon & Tamminga, 2002) and have a negative impact on roadside tree canopy cover, as trees tend to be removed to ensure traffic visibility and safety at intersections (Davies et al., 2008). In terms of road width, previous studies have shown that neighbourhoods with narrow roads have low tree canopy cover (Nagendra & Gopal, 2010; Pham, Apparicio, Landry, & Lewnard, 2017). Insufficient pervious surface often means roadside trees are planted on only one side of narrow roads (Nagendra & Gopal, 2010). Additionally, frequent repairs and improvements to roads and utilities tunnels beneath roads also have the potential to damage roadside trees (Jim, 1998), thus causing tree mortality and removal (Hauer, Miller, & Ouimet, 1994).

Within a neighbourhood, private urban trees are generally located on a number of individual residential properties (Pearce, Kirkpatrick, & Davison, 2013) and affected by individual housing characteristics. For housing type, detached single-unit houses are likely to have larger gardens relative to semi-detached or terraced houses (Troy, Grove, O'Neil-Dunne, Pickett, & Cadenasso, 2007). Unsurprisingly, larger gardens tend to have more space for tree planting and growth (Smith, Gaston, Warren, & Thompson, 2005), but garden size is also determined by parcel shape. Nielsen and Jensen (2015) suggest rectangular parcels in Denmark can have higher tree cover relative to quadratic parcels as property owners would like to plant trees further from houses and rectangular parcels can contain more garden space to achieve this aim. In terms of garden location, its effects on property-scale trees may vary geographically. Front gardens in Hobart, Australia have more intensive landscape than back gardens due to a desire to impress (Daniels & Kirkpatrick, 2006), while back gardens are mainly present in Sheffield probably because front gardens tend to be converted to impervious surfaces by taking away trees and greenspace for access or car parking (Smith et al., 2005).

1.2.4.2 Human Socio-economic Status

Humans have direct influences on urban forest ecosystems. A main conflict between urban forests and population density results from urban land being used for residential dwellings and public infrastructure. Cities with lower population density are more likely to have greater pervious surface and urban forest cover. Other factors also undoubtedly shape urban forest patterns. Socio-economic effects on urban forests cannot be overlooked.

Many cities consist of a variety of ethnic groups, particularly those in countries with high immigration population (UN DESA, 2017). The relationships between urban forest distribution and ethnic group are assorted (Martin, Warren, & Kinzig, 2004; Whitney & Adams, 1980). From the neighbourhood- and property-level perspective, people from different ethnic groups have diverse willingness to manage trees, which is reflected in the ways they practice their garden management. Empirical research has shown lower tree cover falls on neighbourhoods with a high percentage of ethnic minorities (Pham, Apparicio, Landry, Séguin, & Gagnon, 2013), especially when those property owners are likely to rent their properties (Heynen, Perkins, & Roy, 2006; Landry & Chakraborty, 2009). Considering the effect of housing tenure on urban forests, most studies have observed the positive relationship between the rate of ownership and tree canopy cover (Grove, Locke, & O’Neil-Dunne, 2014; Kirkpatrick, Daniels, & Davison, 2011). Property owners have direct legal rights to decide property-scale tree management, and are even obliged to manage gardens following municipal policies (Grove et al., 2014). Indeed, it is not surprising that renters are reluctant to invest in tree planting and management especially if they plan to shift to other residences in the near future (Perkins, Heynen, & Wilson, 2004). Additionally, tree-related benefits lag behind growth and are not immediately perceived, renters are less likely to benefit from planting new trees (Perkins et al., 2004).

The finding that education level affects individual concerns for urban forests has been widely demonstrated in a number of cities and countries. The strongly positive correlation between education level and urban tree cover was reported by Kendal, Williams, and Williams (2012b); Luck, Smallbone, and O'Brien (2009); Pham et al. (2017). Residents with higher education levels may have access to more environmental knowledge and thus better appreciate the valuable benefits from urban trees (Hsu & Roth, 1996; Rajapaksa, Islam, & Managi, 2018). Those residents tend to plant more trees in their properties and even shift to neighbourhoods with more natural amenities (Kendal et al., 2012b). Despite this strong evidence, there are some confounding factors. For instance, there is a high likelihood that education level is related to individual economic status (De Gregorio & Lee, 2002). Therefore, it is also essential to consider the effects of income on inequality of exposure to urban forests. Previous research has highlighted resident economic status as a strong predictor of urban tree cover (Heynen, 2006; Landry & Chakraborty, 2009; Lowry Jr, Baker, & Ramsey, 2012; Steenberg et al., 2015) and survival of tree planting (Vogt, Watkins, Mincey, Patterson, & Fischer, 2015). Affluent areas are likely to have more open space for urban forests (Whitford, Ennos, & Handley, 2001) and affluent individual landowners may actively support urban forest programs (Conway, Shakeel, & Atallah, 2011), which directly contributes to ecosystem services. But, a negative correlation between economic status and urban tree cover was observed by Pauleit et al. (2005) who report that redevelopment in affluent areas of Merseyside reduced public open space and private garden area and thus causing a direct decrease in urban forest cover. This provides an opportunity to hypothesise that the associations between resident socio-economic status and urban forests may be changed due to urban redevelopment.

Apart from those human socio-economic status, housing value as an economic characteristic is also highly influential on property-scale trees. Higher housing value is an identifiable indicator of affluent neighbourhoods in which individual properties are likely to have higher tree cover (Mei, Hite, & Sohngen, 2017), while trees can in turn contribute to high housing value (Krafft & Fryd, 2016; Landry & Chakraborty, 2009; Sander et al., 2010). However, during urban redevelopment, housing redevelopment occurs when the value of new redevelopment exceeds the total value of its existing use and the costs of redevelopment (Brueckner, 1980). Under this economic incentive, it is unclear whether trees are likely to be removed from a property for expanding building footprint to increase housing value.

1.2.4.3 Human Attitudes

Human attitudes including mental, emotional, and behavioural aspects can influence neighbourhood planning (Bohner & Wänke, 2002) and tree management behaviours (Ives & Kendal, 2014). Previous research has given attention to resident attitudes towards urban forests (e.g. Balram and Dragićević, 2005; Jim and Chen, 2006; Lo and Jim, 2012) and urban trees (e.g. Avolio et al., 2015; Kirkpatrick, Davison, and Daniels, 2012; Lohr, Pearson-Mims, Tarnai, and Dillman, 2004; Vesely, 2007) and demonstrated that resident attitudes vary from support to opposition.

People value ecosystem services provided by urban forests (Shackleton, Chinyimba, Hebinck, Shackleton, & Kaoma, 2015). Most studies demonstrate that residents give priority to the aesthetic value of urban forests (Delavari-Edalat & Abdi, 2009). This is especially true when it comes to those who are living in a compact city (Jim & Chen, 2006; Lo & Jim, 2012). Due to urbanisation, many compact cities, such as Hong Kong and Guangzhou, are crowded with massive concrete buildings and impervious pavements, particularly in urban cores. This helps to explain residents' demand for natural amenities (Balram & Dragićević, 2005; Lohr et al., 2004). Meanwhile, many compact cities are suffering from severe environmental issues (e.g. air pollution (Borrego et al., 2006) and heat island effect (Mohajerani, Bakaric, & Jeffrey-Bailey, 2017)); thus, their residents are more likely to aspire to improve their living environment through urban forests providing ecosystem services (Lo & Jim, 2012; Lohr et al., 2004).

Although the problems associated with urban forests are not frequently studied (Vesely, 2007), disservices of urban forests exist and influence human comfort. Firstly, security risks have been highlighted in some studies (Deng, 2015; Michael, Hull, & Zahm, 2001). Residents have concerns that mature trees and shrubs could provide hiding places for criminal activities (Jim & Chen, 2006; Tyrväinen & Miettinen, 2000). In addition, extra municipal expenditure for maintenance and potential damage to public facilities are common worries about urban forests, while allergy and asthma caused by tree pollen could be issues for people who suffer from hypoimmunity (Jim & Chen, 2006; Vesely, 2007).

At the property scale, resident attitudes towards urban forests affect their tree management actions (e.g. tree planting and removal). Similar to resident attitudes towards urban forests, aesthetic value is one of the most important factors that residents invest in tree planting at the property scale (Head & Muir, 2005; Kirkpatrick et al., 2012; Summit & McPherson, 1998). Residents plant trees not only for a desire to enhance kerb appeal (Grove et al., 2006), but also to satisfy their neighbours (Lowry Jr et al., 2012). Additionally, property-scale tree decisions are made due to the functional and economic values provided by trees such as shading for energy savings, increase in property value, and privacy enhancement (Summit & McPherson, 1998).

In contrast, property-scale tree removal is largely attributed to resident concerns about tree health conditions or trees outgrowing the available space. Diseased or aged trees have an increased likelihood of falling or dropping limbs and thus pose a potential risk to houses and people (Terho & Hallaksela, 2004), while tree crowns can deprive residents that desire sun, and roots can damage foundations, paths and pipes when grown proximal to these infrastructure (Morgenroth, 2008; Nicoll & Armstrong, 1998). From the perspective of tree maintenance, some residents believe that fallen leaves, fruit, or flowers can increase the cost or time associated with maintaining their gardens, thus motivating tree removal (Conway, 2016; Summit & McPherson, 1998).

1.2.4.4 Urban Morphological Factors versus Human Factors

Instead of individually examining urban morphological factors or human factors, previous research has concentrated on considering these factors together to explore underlying causes of uneven distributions of urban forests. In general, at the neighbourhood scale, urban morphological factors can predict urban forest cover more so than human factors (Bigsby, McHale, & Hess, 2014; Pham et al., 2017; Pham et al., 2013). As urban forests consist of public and private trees, it is not surprisingly that urban planners and developers rather than residents play a primary role in making decisions about public tree management and may give priority to benefits of constructing more buildings at the expense of urban forests. In contrast, property owners' motivations tend to be relatively more involved in making decisions about private tree management on individual residential properties. As such, it is important to evaluate how changes to property-scale features and human factors affect individual action to tree management, but little research has done that (see an exception Shakeel and Conway (2014)). In the context of urban redevelopment, a focus on property-scale morphological features would neglect residents' socio-economic factors and their attitudes. In contrast, concentrating only on human factors would overlook changes to the physical conditions of properties and how these influence tree dynamics and health condition. As such, to accurately capture urban forest patterns and dynamics resulting from urban redevelopment, it is necessary to consider simultaneously the effects of changes to urban morphology and human factors.

1.3 Knowledge Gap

The studies reviewed in the previous section have demonstrated that urban forests can be affected by urban renewal. In particular, changes to urban morphology during urban renewal have the potential to lead to urban forest loss, while this negative impact could be offset by proper and sustainable urban forest management in the long-term. From the human dimension, urban renewal reshapes neighbourhood socio-economic status and may change the relationship between socio-economic status and urban forest cover. Meanwhile, human attitudes and preferences have also been found to affect urban forests and their management. Overall, at a broad scale, urban morphology presents a stronger impact on urban forest dynamics than human factors (e.g. human socio-economic status, human attitudes). However, in terms of property-scale tree management decisions, it is actors (e.g. property owner, landscape architect, and designer) who directly take responsibility of, and make decisions about, tree management (e.g. tree planting and tree removal) during property redevelopment. Thus, the primary effect of changes to urban morphology on urban forests could be minimised at finer scales.

The fact remains that several knowledge gaps exist in terms of urban forest dynamics during urban renewal. Firstly, few studies establish the relationship between urban forest dynamics and changes to urban morphology over time. As urban forests are dynamic, having a better understanding of how urban forest dynamics respond to urban renewal over time will help urban planners, foresters, geographers, and ecologists to define a canopy cover goal, manage urban forests sustainably, and maximise urban forest ecosystem services. Secondly, little is known about how a complete redevelopment cycle (i.e. building demolition and redevelopment) affects urban trees at the scale of the individual property. Given that most urban renewal is conducted at the property scale, such fine-scale urban tree dynamics can cumulatively shape the broad-scale urban forests. Thus, it is important to capture the nuance in property-scale urban forest dynamics during redevelopment. Thirdly, little research has explored the relationship between resident attitudes towards trees and their tree management actions when undertaking redevelopment. To better understand causative factors of urban forest dynamics during urban renewal, resident attitudes towards trees should be considered because such attitudes may guide residents' decisions about tree removal or planting.

1.4 Research Problem

Christchurch, New Zealand was struck by the 2010 – 2011 Canterbury Earthquake Sequence (CES) (Quigley et al., 2016), which has caused severe damage to thousands of residential properties, rendering them uninhabitable (Christchurch City Council, 2015). Subsequently, the redevelopment of these properties occurred, but the effect of the redevelopment Christchurch's urban forest, at a range of spatial scales, is unknown. Thus, the main research problem is to assess the effect of property redevelopment on Christchurch's urban forest between 2011 and 2015.

Specific research questions to be addressed in this thesis include:

1. How has property redevelopment affected tree canopy cover change across Christchurch?
2. How has property redevelopment affected property-scale tree removal and retention?
3. How has property redevelopment affected resident tree management actions on their properties?
4. How has property redevelopment affected resident attitudes towards tree management actions on their properties?

By addressing these questions, this research will contribute to a better understanding of urban forest dynamics when property redevelopment occurs. Additionally, the outcomes of this research will provide important information for local government in developing long-term urban forest policy and management.

1.5 Thesis Organisation

This research endeavours to answer the research questions proposed in section 1.4, thereby addressing the knowledge gaps identified in section 1.3. To address the first research problem, chapter 2 explores the effects of property redevelopment on urban tree canopy cover change across Christchurch. The analyses in this chapter are conducted at the scale of meshblock. The objectives of this chapter are: 1) to apply the Random Forest classifier to extract tree canopy cover from aerial imagery and LiDAR data; this will allow derivation of canopy cover change between 2011 and 2015; 2) to explore whether tree canopy cover changes unevenly between meshblocks that have experienced property redevelopment versus meshblocks that did not experience property redevelopment; and 3) to explore whether tree canopy cover change is associated with redevelopment density.

Chapter 3 will solve the second research question by exploring fine-scale urban tree dynamics. In this chapter, tree canopy extracted from the remote sensing data in chapter 2 will be refined to capture individual tree dynamics (i.e. tree removal, tree retention) during property redevelopment. The objectives of this chapter are: 1) to quantify property redevelopment's effects on individual tree dynamics; and 2) to identify whether land cover, spatial, economic and socio-demographic variables are useful predictors of property-scale tree removal and retention.

Chapter 4 provides an opportunity to address the third and fourth research question by collecting, via mail questionnaire, resident attitudes towards tree management actions (e.g. tree removal, tree planting). Specifically, chapter 4 explores: 1) residents' tree management actions (i.e. tree removal, tree retention, and tree planting) on their properties between 2011 and 2015; 2) residents' attitudes towards different tree management actions; and 3) whether property redevelopment is a causal factor affecting resident attitudes and actions towards trees.

Chapter 5 summarises all research findings, discusses the contributions of this thesis to previous literature, identifies study limitations and details directions for future research.

Chapter 2

The Effects of Property Redevelopment on Urban Tree Canopy Cover Change

The contents of this chapter have been published as:
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2.1 Introduction

Urban forests provide manifold ecosystem services (Roy et al., 2012). Many studies link ecosystem services to tree canopy cover (TCC) (Donovan & Butry, 2009; McPherson, Simpson, Xiao, & Wu, 2011; Nowak, Hirabayashi, Bodine, & Greenfield, 2014), TCC is easily calculated using a variety of techniques (Parmehr, Amati, Taylor, & Livesley, 2016). As a result, TCC is a simple metric used by researchers and local government urban forest strategy and policy documents (Ordóñez & Duinker, 2013). While higher canopy cover levels are likely to maximise ecosystem services (Lin et al., 2016; Richards & Edwards, 2017), canopy cover is dynamic, continuously changing over time (Nowak & Greenfield, 2012) and space. Additionally, trees and related ecosystem service provisioning is not necessarily equitably distributed throughout cities because of different physical, socio-economic, and policy factors (Escobedo & Nowak, 2009; Fan, Johnston, Darling, Scott, & Liao, 2019; Heynen & Lindsey, 2003; Nesbitt, Meitner, Girling, Sheppard, & Lu, 2019).

Urban forest dynamics are influenced by numerous anthropogenic, edaphic, climatic, and other environmental factors (Conway & Yip, 2016; Lovett et al., 2016; Morgenroth & Armstrong, 2012). A major anthropogenic factor of urban TCC change is urban development, including green- and brown-field development, as well as redevelopment (e.g. intensification and infill development). To accommodate an increasing urban population, associated development will likely affect urban forests (Jim, 1998; Lin, Meyers, & Barnett, 2015; Nowak & Walton, 2005). Urban development often leads to tree removal and reduction in TCC (Morgenroth et al., 2017). Medium- and long-term urban forest effects are less certain, but are dependent upon the remaining available planting space (Attwell, 2000) and also whether trees are planted to replace those removed during development. There is a widely held view that the effects of urban TCC loss may be offset by implementing certain and appropriate urban forest management strategies. For example, various cities have municipal policies or regulations about tree planting and protection (Conway & Urbani, 2007; Hill, Dorfman, & Kramer, 2010; McPherson et al., 2011; Nowak & Greenfield, 2012). These are expected to both directly help sustain public tree cover and require residents to sustain private tree cover (Pincetl, Gillespie, Pataki, Saatchi, & Saphores, 2012; Ruseva, Evans, & Fischer, 2015). From a long-term perspective, when urban trees are planted and properly maintained, their growth and regeneration may cumulatively offset the loss of pre-urban tree cover (Roy et al., 2012).

Most studies exploring the relationships between urban TCC and urban morphology are conducted at a single point in time (Bigsby et al., 2014; Lin et al., 2015; Lowry Jr et al., 2012), but it is important to consider tree canopy change over time for a better understanding of canopy cover dynamics. Remote sensing techniques are an approach to detect urban tree cover change (Kanniah, 2017; Peiman, 2011; Schneider, 2012). Remote sensing techniques can effectively capture data on urban landscape features spanning large regions (Rogan & Chen, 2004) and these data can be stored permanently as satellite imagery, aerial photographs, and LiDAR point clouds for further review or updates. This aids in evaluating the effectiveness of current urban forest management efforts and providing insights into future urban forest management plans (Nowak, 1993).

The study in this chapter explores the effect of property redevelopment on urban TCC change during a five-year period from 2011 to 2015 in Christchurch, New Zealand. Specifically, this study begins by delineating urban tree canopy area from remote sensing data and investigate canopy cover change between 2011 and 2015, and this study then assesses whether unequal change in urban TCC has occurred between redeveloped and non-redeveloped areas. Christchurch provides an intriguing opportunity to study canopy cover dynamics as thousands of properties were demolished and redeveloped after 2010 – 2011 Canterbury Earthquake Sequence (CES) (Quigley et al., 2016), which has been shown to have affected tree cover at small scales (Morgenroth et al., 2017). Whether this holds true at large scales is unknown.

2.2 Methods

2.2.1 Study Area

This study was conducted in Christchurch (Lat: 43.5321° S, Long: 172.6362° E), the largest city in the South Island of New Zealand (Figure 2.1). The study area was determined by the overlapping area of available remotely sensed imagery acquired in 2011 and 2015/16 (Table 2.1). The study area encompasses a total area of 197 km^2. The study will quantify canopy cover at the scale of the study area, and to the smaller scale of meshblocks, which are contiguous geographic boundaries used to define electorates and local authority boundaries. Within the study area, there were 2,012 meshblocks, ranging from 0.002 km^2 to 8.558 km^2 (Mean = 0.091 km^2). Redeveloped properties within the study area were concentrated in the central city and eastern meshblocks (Figure 2.1). The distribution of redeveloped properties reflects that some areas of Christchurch were more affected by the CES than others.

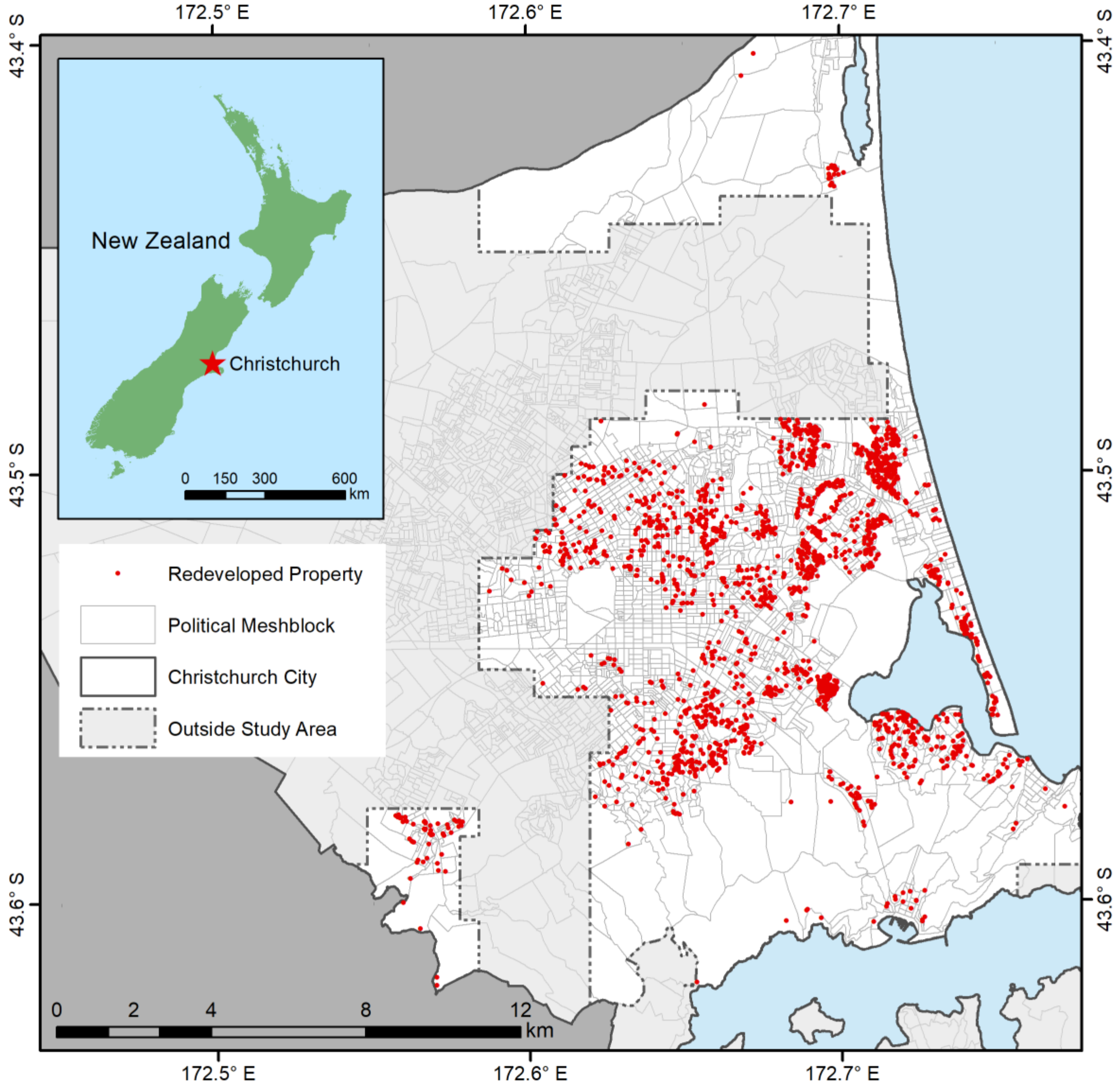

Figure 2.1 – Location of redeveloped properties in Christchurch, New Zealand, as well as, the boundaries for meshblocks and the study area.

2.2.2 Remote Sensing Data Acquisition

The data used for tree canopy mapping included high-resolution aerial imagery and airborne LiDAR point cloud datasets collected in 2011 and 2015/16 (Table 2.1), thereby ensuring a five-year interval to measure urban forest dynamics in Christchurch. Despite the different months of acquisition in the two periods, both acquisitions were conducted during the summer months (leaf-on seasons). Thus, the differing data acquisition periods are not expected to affect classification results.

Table 2.1 – Summary of remote sensing data resources used in this study.

Data Type	**Orthorectified RGB imagery**		**LiDAR**	
Collection Period	24 February 2011	17 November 2015–20 February 2016	8–10 March 2011	31 October–07 November 2015
Spatial Resolution / Average Point Spacing	0.1 m	0.075 m	0.57 m	0.5 m

The 2011 RGB aerial imagery and LiDAR data were supplied by New Zealand Aerial Mapping Ltd (Hastings, New Zealand). These data were captured following the 22 February Christchurch Earthquake and prior to nearly all demolition or redevelopment work (Morgenroth et al., 2017). The aerial photographs were collected using a Vexcel UCXp large format digital aerial camera and projected into the New Zealand Transverse Mercator (NZTM) projection based on the NZGD2000 spheroid. The LiDAR data were captured flying at 900 m above ground level using an Optech Gemini sensor (model # 07SEN211) with settings of 100 kHz pulse rate frequency and 40° full scan angle.

The 2015/16 RGB aerial imagery (hereafter referred to as 2015 aerial imagery) and 2015 LiDAR data were acquired by AAM New Zealand Ltd (Napier, New Zealand) for the Environment Canterbury Regional Council. The aerial photographs over the central business district were captured on 17 November 2015, and the surrounding parts of Christchurch City and Banks Peninsula were captured on 22 January, 10 and 20 February 2016. The 2015 aerial imagery was also supplied in NZTM projection. AAM collected the LiDAR data using an ALS60 system discrete return sensor attached to a fixed wing aircraft. The sensor was configured to record first and last returns with data features of 145 kHz pulse rate frequency and 25° full scan angle. Both 2011 and 2015 LiDAR data were formatted to LAS files, with points classified into ground, non-ground, and water classes.

2.2.3 Tree Canopy Mapping

The workflow for tree canopy mapping started with pre-processing remote sensing data to create elevation- and slope-related surfaces. Combined with aerial imagery, these surface datasets were used for a subsequent object-based image analysis (OBIA) including multi-resolution segmentation and random forest classification. Finally, an accuracy assessment was conducted to determine the veracity of the derived TCC layer. The detailed procedures for tree canopy mapping are as follows.

Initially, two elevation-related surfaces, namely a Digital Elevation Model (DEM) and Digital Surface Model (DSM), were created from raw 2011 and 2015 LiDAR data using a natural neighbour algorithm. DEMs were generated from the classified ground points; DSMs were generated from the first return points. The elevation-related surfaces were interpolated with a spatial resolution of 1 m given that average point spacing of 2011 and 2015 LiDAR data were 0.57 m and 0.5 m, respectively (Table 2.1). Then, normalised Digital Surface Models (nDSM) for 2011 and 2015 were derived by subtracting the DEMs from the DSMs, with a 3×3 moving window focal analysis to minimise the existence of spurious values. Additionally, slope datasets with inclination in degrees were derived from the nDSM datasets. To align with 2011 and 2015 aerial imagery for further image analysis, the 2011 and 2015 nDSM and slope imagery were resampled to a spatial resolution of 0.1 m and 0.075 m, respectively. All processing was carried out in ArcGIS 10.4 (ESRI, 2016).

2.2.3.1 Object-based Image Analysis

This study used an object-based image analysis to map tree canopy in 2011 and 2015. OBIA generally performs better than pixel-based image analysis for land cover classification (Blaschke et al., 2014; Liu & Xia, 2010; Voltersen, Berger, Hese, & Schmullius, 2014; Zhou, 2013). The OBIA approach including segmentation and classification was conducted in eCognition Developer 9.3 (Trimble Navigation Ltd, Sunnyvale, California), using the RGB aerial imagery, nDSM datasets, and slope datasets as inputs (Figure 2.2).

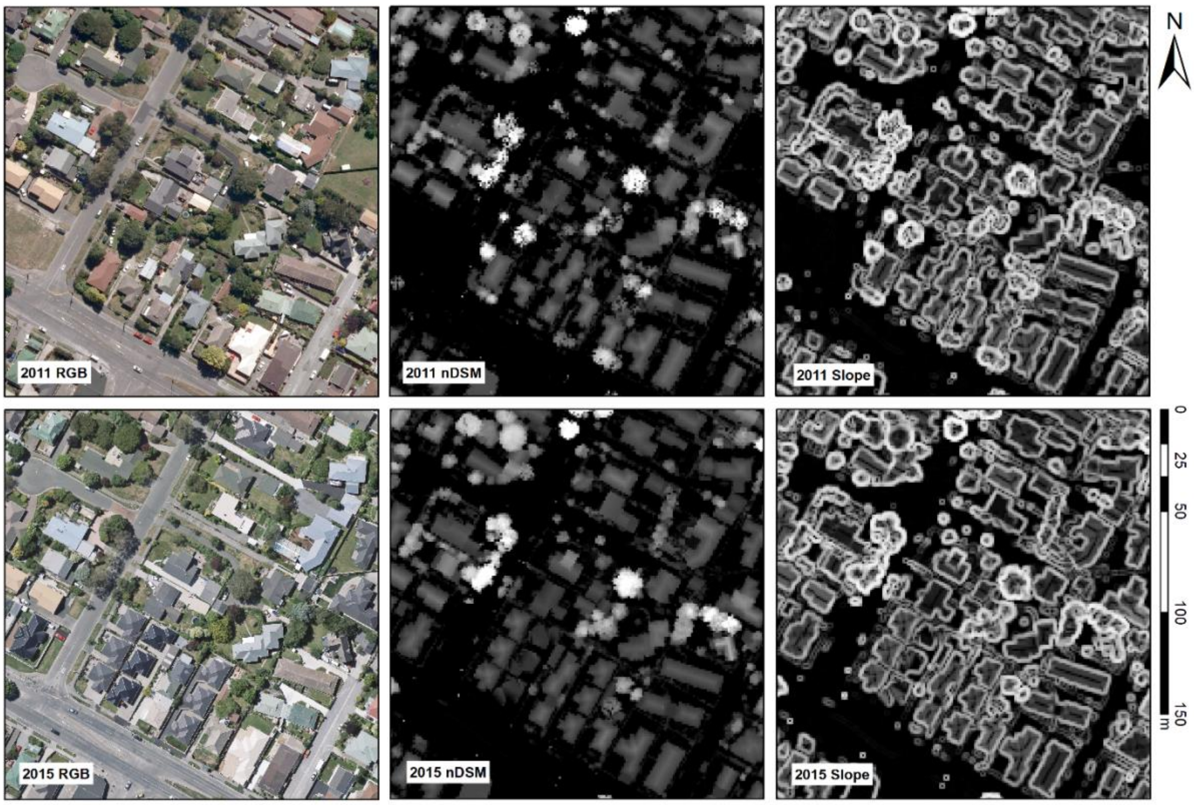

Figure 2.2 – Comparison between 2011 and 2015 input remote sensing datasets for tree canopy mapping. Lighter colours in the nDSM and slope datasets correspond to high values.

2.2.3.2 Segmentation

Segmentation is the process of partitioning an image into image objects with relatively homogenous feature values. Three key criteria, namely scale, shape, and compactness, are generally used to extract meaningful image objects (Tong, Maxwell, Zhang, & Dey, 2012). Of these criteria, the scale parameter is acknowledged as the most important determinant because it defines the maximum homogenous image pixels allowed within image objects (Su & Zhang, 2017). The optimal scale parameters were identified using an Estimation of Segmentation Parameter (ESP) tool (Drăgut, Csillik, Eisank, & Tiede, 2014), as the ESP tool has been successfully used in recent research on land cover classification for error reduction in segmentation (Phiri, Morgenroth, Xu, & Hermosilla, 2018; Xu, Morgenroth, & Manley, 2017; Zhang, Du, & Wang, 2018). Within a segmented image object, the composition of object homogeneity is controlled by shape and compactness parameters (Ma, Cheng, Li, Liu, & Ma, 2015). Shape and compactness parameters were optimised by visually comparing the resulting image objects. Despite being relatively subjective, the visual comparison is accepted as an effective method to evaluate the quality of resulting segmented image objects (Zhang, Fritts, & Goldman, 2008).

This study performed segmentation using a multi-resolution segmentation algorithm (Baatz & Schäpe, 2000), with the optimal parameter values (Table 2.2) and a weight of 1 for all input image layers. A minimum nDSM threshold value of 2.5 m was used for distinguishing tall objects (e.g. trees and buildings) from short objects (e.g. grass land and road). To achieve the main aim of tree canopy mapping, the following classification was only conducted on tall objects.

Table 2.2 – Optimal parameter values for conducting multi-resolution segmentation.

Optimal Parameter Value	2011 input dataset	2015 input dataset
Scale	40	55
Shape	0.1	0.2
Compactness	0.8	0.8

2.2.3.3 Classification

Following an initial classification to separate tall and short objects, the tall objects were classified by Random Forest (RF) classifier (Breiman, 2001). Random Forest classifiers have been increasingly applied in the field of remote sensing image classification (Gislason, Benediktsson, & Sveinsson, 2006; Ham, Chen, Crawford, & Ghosh, 2005; Pal, 2007; Rodriguez-Galiano, Ghimire, Rogan, Chica-Olmo, & Rigol-Sanchez, 2012). This study used a Random Forest classifier to conduct land cover classification due to the need for fewer tuning parameters and more stable classification performance relative to other machine learning methods (Belgiu & Drăguţ, 2016; Li, Ma, Blaschke, Cheng, & Tiede, 2016; Pelletier, Valero, Inglada, Champion, & Dedieu, 2016). The procedure of classification consists of classifier training and trained classifier applying.

This study used training samples and selected features to train the RF classifier. Training sample points (n = 4,000) were randomly generated within the boundary of tall objects with equal sample sizes for tree and building classes. Each sample point was classified as a tree or building by visual inspection of the RGB imagery. With respect to feature inclusion, 38 features were determined for classifier training based on previous literature (Appendix A), including 11 spectral features, 7 textural features, 15 morphological features, 3 LiDAR derived features, and 2 vegetation indices.

The classifier training was conducted with two fixed parameters: 1) the number of decision trees to be produced (Ntree) and 2) the number of randomly selected features for splitting each node (Mtry). The Ntree was set as 500 following the recommendations in previous studies (Belgiu & Drăguţ, 2016; Pal, 2007); the Mtry was equal to the square root of the total number of selected input features (Gislason et al., 2006). Subsequently, the trained classifier was employed to classify tree and building objects.

2.2.4 Accuracy Assessment

Classification accuracy was assessed by a pixel-based comparison between classified data and reference data. Reference data (validation samples) including 500 tree samples and 500 building samples were randomly created over study area. A confusion matrix was produced, then overall accuracy (OA), producer's accuracies (PA) and user's accuracies (UA) were calculated (Congalton & Green, 2009). OA is used to evaluate the overall performance of classification results, while PAs and UAs are used to understand classification performance of individual classes.

2.2.5 Residential Property Redevelopment

To assess the influence of residential property redevelopment on TCC change between 2011 and 2015, 2,835 residential properties were identified as potential redeveloped properties from a list of Code of Compliance Certificates (CoCC) issued by the Christchurch City Council. CoCCs are issued upon completion of a property's redevelopment. However, the CoCC list encompassed all types of property redevelopment (e.g. renovation and demolition) and this study was only interested in properties that underwent complete redevelopment. To refine the initial CoCC list, a visual assessment was employed to exclude properties that had not been fully redeveloped by comparing 2011 and 2015 aerial imagery. Criteria for redevelopment property inclusion were: 1) a building had not been demolished on 2011 aerial imagery; and 2) the property had been completely redeveloped on 2015 aerial imagery. Complete redevelopment includes change in building footprint or change in building position within a property.

From the initial CoCC list of redeveloped properties, 1,956 met the criteria and were included in the study.

The redeveloped properties were used to separate redeveloped and non-redeveloped meshblocks. A meshblock was identified as redeveloped if there was at least one property that had been completely redeveloped between 2011 and 2015, while a non-redeveloped meshblock did not contain any properties that were redeveloped between 2011 and 2015.

2.2.6 Statistical Analysis

Firstly, a paired-sample t-test was used to compare TCC of meshblocks in 2011 and 2015. This study chose meshblock as an analytical unit because similar geographical units (e.g. census tract and block) are commonly used for exploring uneven access to urban trees (Greene, Robinson, & Millward, 2018; Steenberg, Robinson, & Duinker, 2018; Troy et al., 2007). The TCC was determined by tree canopy area (TCA) datasets derived from the classification results. In the study, changes in TCC were analysed by excluding large-scale forest plantations from the TCA datasets. This was done to limit the short-term effect of forestry activities (e.g. thinning, harvesting, and planting). TCC changes, inclusive of large-scale forest plantations were also calculated, but for the sake of brevity are not included in the results (see Appendix B). For each meshblock, absolute and relative TCC change were calculated as in Equation (1) and (2), respectively. Subsequently, independent sample t-test was used to test for the discrepancy in TCC change between redeveloped and non-redeveloped meshblocks. Finally, a Pearson correlation analysis was conducted to explore the relationship between TCC change and redeveloped density at the meshblock scale. Redevelopment density was defined as in Equation (3). Meshblock redevelopment density data were transformed (Log_{10}) prior to further correlation analyses to minimise the strong positive skewness in the raw data.

$$\text{Absolute } TCC_{change} = (TCA_{2015} - TCA_{2011}) \times MA^{-1} \qquad \text{Equation (1)}$$

$$\text{Relative } TCC_{change} = (TCA_{2015} - TCA_{2011}) \times TCA_{2011}^{-1} \qquad \text{Equation (2)}$$

where, TCA_{2011} is the tree canopy area in 2011 and TCA_{2015} is the tree canopy area in 2015, while MA is the area of meshblock. A positive TCC_{change} value means TCC gain, while a negative value means TCC loss.

$$\text{Redevelopment}_{density} = N \times MA^{-1} \qquad \text{Equation (3)}$$

where, N is the number of redeveloped properties.

2.3 Results

2.3.1 Classification Accuracy Assessment

The classification accuracy assessments for 2011 and 2015 tree canopy mapping are shown in Table 2.3. The overall accuracy of the 2015 classification (97.2 %) was slightly higher than that of the 2011 classification (95.7 %). Both these accuracies generally exceed those in studies applying the pixel-based approach, in contrast to the object-based approach (e.g. Van De Voorde, De Genst, & Canters, 2007) or those studies classifying multispectral imagery without LiDAR data (e.g. Baker, Smith, & Cavan, 2018; Pu, Landry, & Yu, 2011). Kappa values of 2011 and 2015 accuracy assessments indicate a strong possibility that assessment agreement occurs beyond chance. User's and Producer's accuracies show that individual classes were neither over- nor under-classified.

Table 2.3 – Confusion matrix for 2011 and 2015 classification accuracy assessment.

	Classified Data	Reference Data		Total	User's Accuracy
		Tree	Building		
2011	Tree	483	26	509	94.9%
	Building	17	474	491	96.5%
	Total	500	500	1000	
	Producer's Accuracy	96.6%	94.8%		
	Overall Accuracy	95.7%			
	Kappa Statistic	0.914			
2015	Tree	482	10	492	98.0%
	Building	18	490	508	96.5%
	Total	500	500	1000	
	Producer's Accuracy	96.4%	98.0%		
	Overall Accuracy	97.2%			
	Kappa Statistic	0.944			

2.3.2 Tree Canopy Cover Change

The percentages of TCC over the study area in 2011 and 2015 were 10.8% (tree canopy area = 21.4 km2) and 10.3% (tree canopy area = 20.3 km2), respectively. If plantation forest area is included, these figures increase to 13.4% (tree canopy area = 26.4 km2) and 11.8% (tree canopy area = 23.3 km2), respectively (Appendix B). The total tree canopy area decreased by 1.1 km2 between 2011 and 2015. TCC loss occurred in 1,191 (59%) meshblocks, while 819 (41%) meshblocks gained TCC (Figure 2.3). The results of paired samples t-test show that there was a significant difference ($p < 0.001$, $t(2011) = 12.49$) between mean TCC in 2011 (M = 11.5%, S.E. = 0.2%) and mean TCC in 2015 (M = 10.7%, S.E. = 0.2%). These results suggest that tree canopy changed significantly, but the changes were not evenly distributed across meshblocks (Figure 2.3).

2.3.3 Effects of Redevelopment on Tree Canopy Cover Change

Of the 2,012 meshblocks over the study area, 712 (35%) included redeveloped properties, while 1,300 (65%) were non-redeveloped. The results from independent sample t-test to test for the effect of redevelopment on TCC change are shown in Table 2.4. On average across all meshblocks, TCC loss occurred during the analysis period, and loss in redeveloped meshblocks (1.3% absolute TCC loss; 4.1% relative TCC loss) was significantly greater than in non-redeveloped meshblocks (0.5% absolute TCC loss; 8.4% relative TCC gain). But, the correlation analysis for the effect of redevelopment density on both absolute and relative TCC loss at the meshblock scale did not show a statistically significance. This implies that although redeveloped meshblocks were more likely to have canopy loss, loss was not affected by redevelopment density.

Table 2.4 – Summary statistics for tree canopy cover and tree canopy cover change on redeveloped versus non-redeveloped meshblocks. Statistically significant differences within each metric were tested for with independent sample t-test and are noted by "*": $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

Metric	Redeveloped Meshblock (n = 712)	Non-redeveloped Meshblock[1] (n = 1298)
	Mean (Standard Error)	Mean (Standard Error)
Tree Canopy Cover in 2011***	12.6% (0.3%)	10.9% (0.2%)
Tree Canopy Cover in 2015**	11.3% (0.2%)	10.4% (0.2%)
Absolute Tree Canopy Cover Change***	-1.3% (0.1%)	-0.5% (0.1%)
Relative Tree Canopy Cover Change***	-4.1% (1.4%)	8.4% (1.8%)

1. The total number of non-redeveloped meshblocks is 1300, but two of the non-redeveloped meshblocks where no tree canopy covered in 2011 and 2015 were excluded in the independent sample t-test analyses.

2.4 Discussion

This study shows that TCC across the study area has declined 1.1 km^2 during analysis period. The causes for canopy cover decline are likely manifold and complex. Firstly, the analysed area centred on a relatively major urban area that was affected by the 2010 – 2011 Canterbury Earthquake Sequence

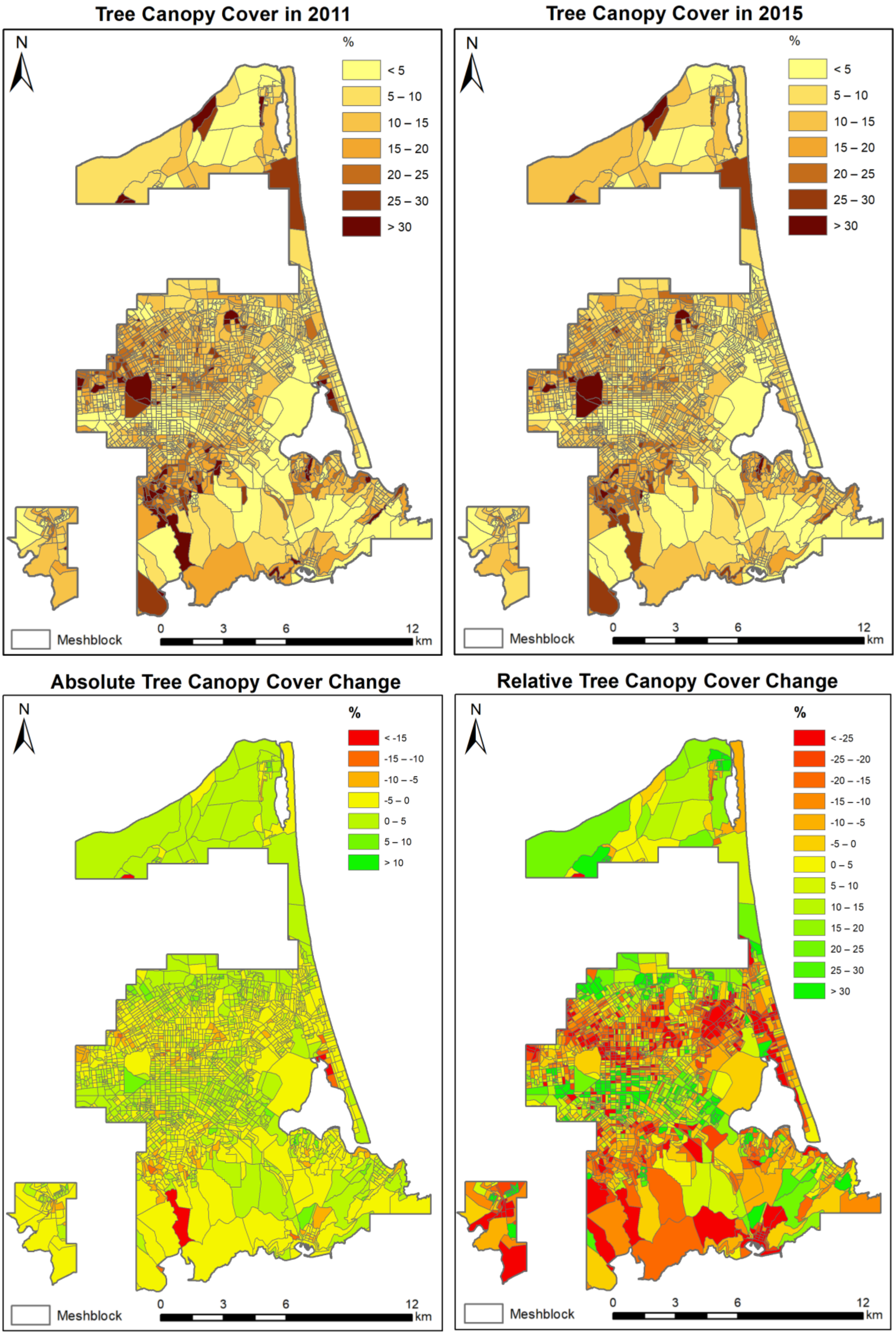

Figure 2.3 – Tree canopy cover change and tree canopy cover in 2011 and 2015.

(CES). The 2010 – 2011 CES had direct and indirect impacts on urban forest dynamics in Christchurch, New Zealand (Morgenroth & Armstrong, 2012; Quigley et al., 2016) and resulted in changing soil environments (e.g. soil liquefaction, rockfalls, landslips, changing water table depth) that affected tree root systems, causing structural damage, health decline, or death (Morgenroth & Armstrong, 2012). The removal of the affected trees may have been undertaken to minimise risk to people and property. A previous localised study conducted in the city centre of Christchurch shows TCC loss was related to property demolition (Morgenroth et al., 2017). However, such loss caused by urban development should be cautiously assessed as tree growth and regeneration may offset the effects of tree loss over time (Berland, 2012).

Despite a small magnitude of absolute loss in TCC occurring in the context of study area, but TCC has significantly changed across all the meshblocks. Redeveloped meshblocks were more likely to incur TCC loss (1.3% absolute TCC loss; 4.1% relative TCC loss). This supports previous studies that have highlighted urban redevelopment as one of the most influential factors to cause uneven distribution of urban forests (Brunner & Cozens, 2013; Dallimer et al., 2011; Jim, 1998). Property redevelopment provides opportunities for increased building footprint and impervious surface (Lee et al., 2017), both of which can be achieved by removing existing trees. Meanwhile, trees retained during redevelopment may not be immune to the effects of construction activities (e.g. excavating soil, setting out building foundation, and installing sewer pipes). These activities often result in root damage or severance, which has been demonstrated to negatively impact tree function, growth, and stability (Benson, Koeser, & Morgenroth, 2019; Benson, Morgenroth, & Koeser, 2019; Watson, Hewitt, Custic, & Lo, 2014). Koeser et al. (2013) reported that trees adjacent to construction activities were twice as likely to die in contrast with those unaffected trees.

Interestingly, further exploration of the influential magnitude of redevelopment on TCC change in this study did not show a statistically significant correlation between redevelopment density and TCC loss. This may be explained by the process of identifying redeveloped residential properties for inclusion in this study. When identifying residential property redevelopment, this study constrained the analysis to those properties that had undertaken a complete redevelopment, including demolition of the old building and construction of the new building, rather than those properties with other types of development (e.g. only demolition, renovations, or new structures being built on vacant land). By excluding these less invasive forms of development, the reported effects of property redevelopment on urban forest dynamics may be an underestimate.

Like other studies before it (Greene et al., 2018; Steenberg et al., 2018), this study was conducted at the scale of the meshblock. But, the scale of these analyses aggregate tree cover dynamics over the area within the meshblock boundary, obscuring the impact of individual residential properties. In Christchurch, a large majority of urban trees (74.9%) are located on private property (Morgenroth, 2017) and are managed by private landowners. The tree management decisions made on individual properties may fail to affect urban forest dynamics at the scale of the meshblock, but could have more localised effects. Thus, disaggregating the meshblock TCC data to a finer scale boundary (e.g. individual property) may yield different outcomes and better explain the nuance of urban forest dynamics.

The urban forest metric applied in this study may also have contributed to the ambiguous relationship between redevelopment and urban forest dynamics. This study used TCC as the response variable because it is associated with urban ecosystem services and aesthetic value (McPherson et al., 2011) and is a typical metric found in numerous local government urban forest strategy or policy documents (Ordóñez & Duinker, 2013). Despite this, TCC is coarse, and does not provide opportunities to differentiate between individual trees and describe the diversity of urban forests (Morgenroth & Östberg, 2017). As the discrepancy of demolition's effects on large and small trees has been observed in Christchurch (Morgenroth et al., 2017), it may be important to consider individual trees when assessing the effects of redevelopment on urban forest dynamics. As such, future research could consider urban forest metrics other than canopy cover (e.g. individual trees, stem density, leaf area, and stem basal area) for monitoring urban forest dynamics to have a better understanding of the relationship between urban trees and property redevelopment.

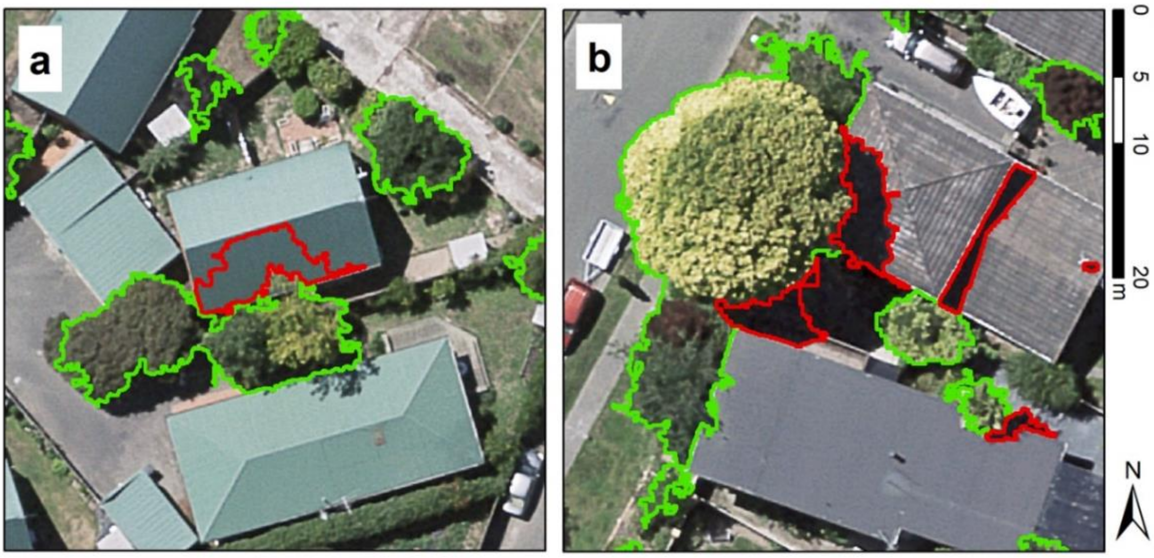

Figure 2.4 – Misclassifications of tree canopy. Non-tree objects (red polygon) that are misclassified as trees (green polygon) include: a) misclassified building roofs and b) misclassified shadows.

Because this study compared TCC change on redeveloped and non-redeveloped properties in Christchurch, it was dependent on accurate quantification of tree cover in both 2011 and 2015. While the Random Forest classifier produced higher classification accuracies for the tree canopy class, some misclassifications occurred, which affected the accuracy of TCC change values and may have contributed to the small magnitude of changes in TCC during the analysis period. While the LiDAR data allowed us to utilise elevation information to separate objects that share similar spectral and textural information but differ in height such as trees and shrubs, the threshold value of 2.5 m set in this study to distinguish tall and short objects may have excluded some short trees. For example, newly planted trees are likely to be short (tree height < 2.5 m) and have small crowns, and thus were likely to be misclassified as non-tree objects. In contrast, among tall objects, misclassifications were mainly caused by spectral similarities between materials of building roofs and adjacent trees (Figure 2.4a) as well as shadows (Figure 2.4b). Due to lack of near-infrared band in the aerial imagery, this study could not calculate the Normalized Difference Vegetation Index (NDVI) that has been highlighted as a useful aid to extract urban tree canopy (Alonzo, Bookhagen, & Roberts, 2014; Ke, Im, Lee, Gong, & Ryu, 2015) and measure urban forest dynamics (Ossola & Hopton, 2018). Future research could introduce NDVI to reduce such misclassifications and optimise classification results.

2.5 Conclusion

Redevelopment of urban areas worldwide has the potential to affect urban forests which are relied upon for numerous ecosystem services. This study explored the effect of redevelopment on urban TCC change in Christchurch, New Zealand where thousands of properties were demolished and rebuilt after the 2010 – 2011 Canterbury Earthquake Sequence.

By applying the Random Forest classifier to aerial imagery and LiDAR data, this study extracted tree canopy in 2011 and 2015 with high classification accuracies (>95%), which provided a solid foundation for subsequently monitoring TCC change. The results show a relatively minor change in TCC over the study area during the analysis period, but TCC significantly changed across meshblocks. Redeveloped meshblocks experienced greater levels of TCC loss than non-redeveloped meshblocks. However, TCC loss was insensitive to meshblock redevelopment density. This may result from the choice of geographic unit (i.e. meshblock) or the response variable (i.e. canopy cover). To better understand the effect of redevelopment on urban forest dynamics, further research should consider analysis at a finer scale and assessment of different urban forest metrics as response variables.

Chapter 3

The Effects of Property Redevelopment on Property-scale Tree Removal and Retention

The contents of this chapter have been published as:
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3.1 Introduction

Despite the benefits provided by urban forests (Roy et al., 2012), tree canopy cover decline in cities is common (Chuang et al., 2017; Nowak & Greenfield, 2018). There are a variety of reasons that urban trees are removed – some are dead, some are senescent, some have actual or perceived risk, and some are healthy but are removed nonetheless.

Recent studies have explored tree canopy cover reduction associated with factors such as disease and pest infestation (Lovett et al., 2016), environmental pollution (McLaughlin, 1998), and climate change (Tubby & Webber, 2010). Urban trees are also vulnerable to severe weather (e.g. ice storms (Conway & Yip, 2016), drought (Holopainen, Leino, Kämäri, & Talvitie, 2006)) and natural disasters (e.g. hurricanes (Thompson, Escobedo, Staudhammer, Matyas, & Qiu, 2011) and earthquakes (Morgenroth & Armstrong, 2012)), which can lead to tree canopy loss. Additionally, urban development, including greenfield development and redevelopment of existing urban areas, is often reported as a major factor in reducing tree cover (Jim, 1998; Nowak & Greenfield, 2012, 2018; Nowak & Walton, 2005), although tree cover can recover or even increase with time after development, assuming new trees are planted or allowed to naturally regenerate.

Generally, studies on canopy cover reduction are conducted at the scale of a city (Hostetler et al., 2013; Nowak & Greenfield, 2012) or country (Nowak & Greenfield, 2018). But, cities are agglomerations of private and public properties, a consequence of which is fractured land ownership, such that fine-scale processes and decisions can cumulatively have effects on the whole of the urban forest. Instead of exploring urban canopy cover decline at a broad scale, some recent studies have focused on fine-scale tree loss on individual properties and the variety of factors involved in tree removal. One driver of tree removal is poor tree health or perceived risk, as landowners may be concerned about hazards caused by falling limbs or trees (Conway, 2016; Kirkpatrick et al., 2012; Summit & McPherson, 1998). Another factor contributing to tree removal is individuals' preferences for landscaping style (Kirkpatrick, Davison, & Daniels, 2013).

Given the negative relationship between tree canopy cover and development at broad-scales (Jim, 1998; Nowak & Greenfield, 2012, 2018; Nowak & Walton, 2005), it is likely that fine-scale tree loss is also influenced by development, however relatively few studies have considered this. Previous studies have shown that tree loss is correlated with building permits being issued (Steenberg et al., 2018), demolition activities (Morgenroth et al., 2017), and new development or redevelopment (Koeser et al., 2013). The study in this chapter adds to the small, but growing body of research on the fine-scale relationship between tree loss and development.

Specifically, this chapter will (1) quantify the effect of property redevelopment on tree removal and retention and (2) identify other land cover, spatial, economic and socio-demographic variables related to tree removal and retention on residential property. These objectives are addressed in Christchurch (New Zealand), which provides an interesting case study where a large number of residential properties were redeveloped over a short-period of time after the 2010-2011 Canterbury Earthquake Sequence (CES) (Quigley et al., 2016). The study is conducted at the scale of the individual tree, thus it will provide a more nuanced understanding of the factors that contribute to tree removal and retention during redevelopment activities.

3.2 Methods

3.2.1 Study Area

The study was conducted in Christchurch, New Zealand (Lat: 43.5321° S, Long: 172.6362° E) (Figure 3.1). Christchurch has approximately 16% tree canopy cover varying from 7% to 29% in different wards (Morgenroth, 2017). Public greenspace is primarily composed of exotic plant species, while private greenspace mostly consists of native species (Stewart, Ignatieva, Meurk, & Earl, 2004).

Christchurch was struck by a series of major earthquakes, the CES, with the largest occurring on 4 September 2010 and 22 February 2011 (Quigley et al., 2016). After the 2010-2011 CES, 10,000 – 15,000 properties were estimated as being severely damaged and rendered uninhabitable (Christchurch City Council, 2015). Demolitions and redevelopment of these properties, concentrated in the central city and eastern suburbs, are ongoing. The individual properties included in the study (Figure 3.1) reflect that some areas of Christchurch were more affected by land and property damage than others.

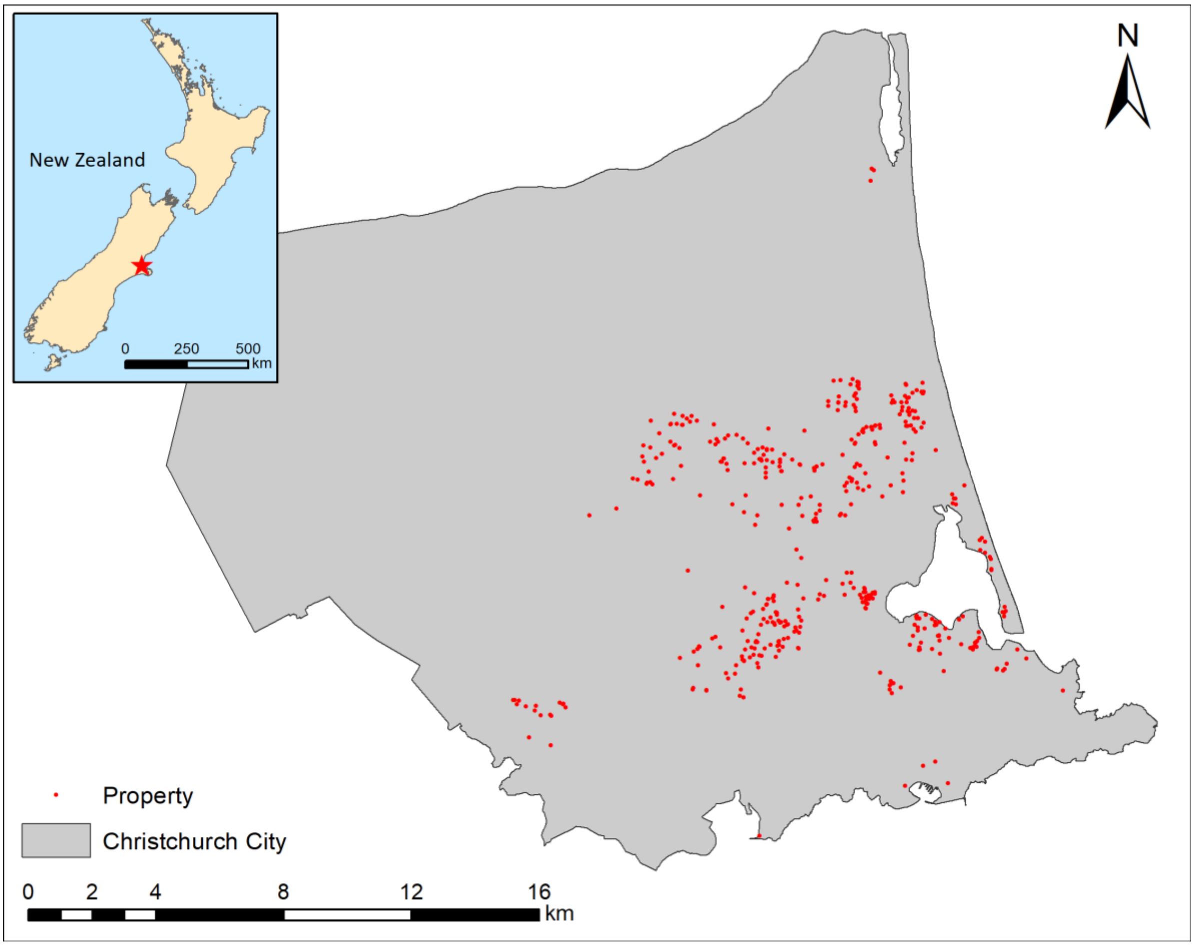

Figure 3.1 – Dots show individual residential properties included in the study.

3.2.1.1 Residential Property Sample

This study used a sample of trees located on redeveloped and non-redeveloped residential properties. An initial group of 2,835 residential properties, where dwellings had been redeveloped between 22 February 2011 and 17 November 2015, was obtained from a list of Code of Compliance Certificates issued by the Christchurch City Council. The Code of Compliance Certificate list also included properties which underwent less significant forms of development (e.g. renovation), but these were excluded from this study. Only properties that had undergone complete demolition and redevelopment were included. In some instances, the redevelopment involved demolition of a damaged structure and subsequent construction of a new structure with the same building footprint and the floor area. In other cases, a damaged structure was replaced with a new structure having a larger building footprint or increased floor area.

This initial group of redeveloped residential properties were geocoded and overlaid on aerial photographs and LiDAR imagery that were acquired immediately following the earthquakes in 2011 and again in 2015 – 2016 (Table 3.1). These remote sensing data sources were used to extract individual trees and potential variables to explain the reasons for trees being removed or retained on each property (described in section 3.2.2.2 below). Some of the redeveloped properties were located outside the boundary of overlapping imagery; because it would not be possible to extract variables for these properties, they were eliminated from the study.

Table 3.1 – Summary of remote sensing data resources acquisition. 1 – Supplied by New Zealand Aerial Mapping Ltd. (Hastings, New Zealand). 2 – Supplied by AAM New Zealand Ltd. (Napier, New Zealand).

Data	Acquisition Date	Spatial Resolution/Average Point Spacing
2011 Orthorectified RGB imagery[1]	24 February 2011	0.1 m
2011 LiDAR[1]	8–10 March 2011	0.57 m
2015/16 Orthorectified RGB imagery[2]	During the summer of 2015-16	0.075 m
2015 LiDAR[2]	31 October–07 November 2015	0.5 m

Next, each potential redeveloped residential property was compared in the 2011 and 2015/16 aerial photographs. Properties were included in the study if their primary dwelling had not been demolished at the time of the 2011 aerial photographs, but had been completely demolished and rebuilt, including completed landscaping activities, at the time of the 2015/16 aerial photographs. Of all the potential redeveloped residential properties, 1,956 met these criteria and were included for further analysis.

For each redeveloped residential property, a non-redeveloped control property was also included in the study. All properties bordering each redeveloped property were identified as potential non-redeveloped residential properties. One non-redeveloped property was randomly selected from this set of potential non-redeveloped properties. If all residential properties bordering the redeveloped property had also been redeveloped, the nearest non-redeveloped residential property (straight line distance) within the same meshblock was selected.

Residents of the 3,912 properties were then mailed a survey to collect data about their household. In October 2016, surveys were sent to the 1,956 redeveloped residential properties. Of the 1,956 surveys mailed to redeveloped properties, 489 were returned (response rate = 25%). Of these, only 321 (16%) were complete and able to be used in the analysis. Surveys were sent to the 1956 non-redeveloped residential properties in January 2017. Of the 1956 surveys mailed to the non-redeveloped properties, 325 were returned (response rate = 17%). However, of these, only 129 (7%) were complete and able to be used. No follow-up contact was made with prospective respondents who did not return completed surveys. The two primary reasons for excluding returned surveys were missing data or participants not meeting a study condition. With respect to missing data, many participants were reluctant to provide information such as gender, religion, or annual household income and without these, surveys were excluded. Additionally, a condition of inclusion in the study, was that participants were living at the property at the time of the 2011 earthquakes. Thus, the final sample included 450 properties (321 redeveloped, 129 non-redeveloped).

3.2.2 Data and Analysis

The relationship between tree status (whether the tree was removed or retained), and a variety of explanatory variables was explored at the individual tree-scale using a Classification Tree (CT) analysis. The candidate explanatory variables were identified based on existing literature focusing on urban forest dynamics. They were categorised as resident and household variables, economic variables, spatial variables, and land cover variables. Explanatory and response variables were collected via multiple methods, including a questionnaire survey, remote sensing analysis, and acquisition of official government data (Table 3.2).

3.2.2.1 Explanatory Variables

3.2.2.1.1 Resident and Household Data

Resident and household data were composed of property-scale survey data and meshblock-scale population density. Survey data were collected via a mail-based questionnaire survey conducted during the summer of 2016 – 2017 (see a sample in Appendix C). The survey was targeted at the primary decision maker in the home and was separated into two sections. The first section asked participants about residency information, including whether participants were living at their address during the CES, to make sure they met the sample criteria, and whether their properties had been demolished and rebuilt after the major earthquakes. The second section asked participants about resident and household information including gender, age, ethnicity, religion, education level, and annual household income. Meshblock-scale population density for 2013 was obtained from Statistics New Zealand, such that each property was assigned a population density corresponding to the meshblock it falls within.

3.2.2.1.2 Economic Data

Five economic variables were included in the model. A meshblock-scale deprivation index for 2013 was acquired from the Ministry of Health, while annual household income was collected from 2016-17 surveys. Property-scale capital value (CV), land value, and improvements value in 2016 were obtained from the Christchurch City Council. CVs are used by the city council for taxation purposes and provide an estimate of the value of a property. CVs include both land value and improvements value (buildings on the property).

Table 3.2 – Summary of candidate explanatory variables included in the classification tree analysis (n = 450).

	Variable Name	Description	Data Source	Mean	Range/Percent Yes
Resident and Household Variables	Pop_Density_2013_MB	Continuous: Number of residents per square kilometre in 2013 on meshblock level (per km^2)	Statistics New Zealand	1,976	36-6,071
	Gender	Categorical: Gender of homeowner	Survey (2016-17)	-	-
	Age	Continuous: Age of homeowner	Survey (2016-17)	62	18-100
	Ethnicity	Categorical: Ethnicity of homeowner	Survey (2016-17)	-	-
	Religion	Categorical: Religion of homeowner	Survey (2016-17)	-	-
	SSQ	Categorical: Achieved secondary school qualification (Yes)/Without secondary school qualification (No)	Survey (2016-17)	-	85
	PSSQ	Categorical: Achieved post-secondary school qualification (Yes)/Without post-secondary school qualification (No)	Survey (2016-17)	-	72
Economic Variables	NZDep2013_MB	Continuous: Index of deprivation in 2013 on meshblock level	New Zealand Ministry of Health	3	1-10
	CV_2016	Continuous: Capital value in 2016 (000s NZD)	Christchurch City Council opendata	714	195-3,270
	LV_2016	Continuous: Land value in 2016 (000s NZD)	Christchurch City Council opendata	249	45-1,540
	IV_2016	Continuous: Improvements value in 2016 (000s NZD)	Christchurch City Council opendata	465	61-2,395
	Household_Income	Categorical: Annual household income in 2016 (1000 NZD)	Survey (2016-17)	-	-
Spatial Variables	Dist_Parcel_To_Reserve_2011	Continuous: Linear distance of property centre to the nearest greenspace (m)	Canterbury maps opendata	143.1	7.2-633.4
	Dist_Tree_To_Driveway_2011	Continuous: Linear distance of each tree crown boundary to the residential property's driveway (m)	-	13.7	0-71.6
	Dist_Tree_To_Building_2011	Continuous: Linear distance of each tree crown boundary to the nearest building within the same residential property (m)	-	6	0-60

Continued on next page

	Variable Name	Description	Data Source	Mean	Range/Percent Yes
Land Cover Variables	Parcel_Area	Continuous: Area of property parcel (m^2)	NZ Primary Parcels[1]	965	262-3,997
	Building_Cover_2011	Continuous: Area of building footprint in 2011 to parcel area ratio (%)	Christchurch Post-Earthquake 0.1m Urban Aerial Photos (24 February 2011)[1]	26	3-62
	Building_Cover_2015	Continuous: Area of building footprint in 2015 to parcel area ratio (%)	NZ Building Outlines (Pilot)[1]	28	3-60
	Impervious_Cover_2011	Continuous: Area of impervious ground cover (parcel area-hard and impervious area within a property) in 2011 to parcel area ratio (%)	-	74	38-97
	Impervious_Cover_2015	Continuous: Area of impervious ground cover (parcel area-hard and impervious area within a property) in 2015 to parcel area ratio (%)	-	72	40-97
	Building_Status	Categorical: Redeveloped building (Yes)/Non-redeveloped building (No)	Christchurch 0.075m Urban Aerial Photos (2015-16)[1]; Christchurch Post-Earthquake 0.1m Urban Aerial Photos (24 February 2011)[1]	-	70
	Rd_Area_MB	Continuous: Road area on meshblock level (m^2)	NZ Primary Road Parcels[1]	17,128	3-254,768
	Rd_Cover_MB	Continuous: Road area on meshblock level to meshblock area ratio (%)	-	17	0-40
	TreeC_2011	Continuous: Tree crown area in 2011 (m^2)	Christchurch Post-Earthquake 0.1m Urban Aerial Photos (24 February 2011)[1]	12.7	0.4-511.7
	TreeH_2011	Continuous: Tree height in 2011 (m)	Christchurch City Council (March 2011)	5.4	2.5-28.5
	TreeV_2011	Continuous: Tree crown volume in 2011 (m^3)	-	94	1-11,671
	TCC_2011	Continuous: Tree canopy cover in 2011 (%)	-	35	0-112

1. LINZ data service.

3.2.2.1.3 Land Cover Data

Potential explanatory land cover variables related to the amount and proportion of building cover, tree cover, and impervious cover for each property were derived in a GIS or from remotely sensed data (Table 3.2). Property boundaries (LINZ, 2016) were used to calculate land cover variables at the property scale. The land cover analysis was based on two sets of aerial photography and LiDAR data, covering two time periods: 2011 and 2015/16 (Table 3.1).

LiDAR data were used to produce two surfaces, namely a Digital Elevation Model (DEM) and Digital Surface Model (DSM) with a spatial resolution of 0.1 m. DEMs were interpolated from the ground returns; DSMs were interpolated from the first returns using a natural neighbour algorithm. Subsequently, normalised Digital Surface Models (nDSM) for 2011 and 2015 were derived by subtracting the DEMs from the DSMs. A 3 x 3 moving window focal analysis was used to minimise the existence of spurious values in the nDSMs. All processing was conducted in ArcGIS 10.4 (ESRI, 2016).

A land cover classification was undertaken in eCognition (Trimble, Sunnyvale, CA, USA), an object-based image analysis software package. A classification ruleset was created to segment the nDSM and orthorectified aerial imagery into objects, which were subsequently classified into three classes: buildings, trees and short objects. A mean nDSM threshold value of 2.5 m differentiated short objects from buildings and trees, while spectral values from orthophotos distinguished buildings from trees. A comparable version of the classification ruleset has been previously described (Morgenroth et al., 2017). Land cover boundaries within each of the 450 properties were then manually refined to increase accuracy. For example, the edges of building objects were corrected using the NZ Building Outlines dataset (Table 3.2) as a guide. Buildings misclassified as trees and vice-versa were also corrected. Land area classified as short objects in the automated land cover classification were manually refined to specifically delineate any pavements (asphalt, concrete, and brick), which were classified as impervious cover.

3.2.2.1.4 Spatial Data

Several variables describing spatial relationships were also included in the analysis. ArcGIS 10.4 was used to determine the linear distance between each residential property and the nearest greenspace, the linear distance between each tree crown boundary and the residential property's driveway, and the linear distance between each tree crown boundary and the nearest building within the same residential property.

3.2.2.2 Response Variable – Tree Removal and Retention

To create the binary response variable (removed or retained), the tree land cover class was further refined by manually delineating individual trees. This allowed clear identification of those that were present in 2011 and either retained or removed by 2015/2016. Each of the 6,966 trees identified in the 2011 imagery was assigned a status (i.e. removed, retained) by visually comparing aerial photographs between the two time periods (Figure 3.2). Trees that were present in the 2011 aerial photographs but absent in the 2015/16 photographs were categorised as a removed tree, while trees that present both in the 2011 and 2015/16 aerial photographs were classified as a retained tree. The land cover classification process (section 3.2.2.1.3) failed to consistently identify trees that had been planted between 2011 and 2015/16. This is because newly planted trees generally failed to meet the 2.5 m height threshold that was used to define trees. As such, a decision was made to exclude newly planted trees from the analysis.

Figure 3.2 – Trees present in the 2011 aerial photograph (left) and the 2015/16 aerial photograph (right) on a redeveloped residential property. The red boundary is the property boundary. In the 2011 aerial photograph, the yellow polygons show trees that were removed, while the blue polygons show the trees that were retained following redevelopment.

3.2.2.3 Analysis

3.2.2.3.1 Modelling Tree Removal and Retention

This study used a Classification Tree to model the relationship between tree status (i.e. removed, retained) and candidate explanatory variables. CTs can be interpreted easily via graphical outputs and can handle data auto-correlation as well as combinations of continuous and categorical variables. Moreover, CTs have previously been used successfully in comparable studies (Morgenroth et al., 2017).

CTs were grown by recursively partitioning the tree status dataset into mutually exclusive binary subsets. Each subset is maximally homogeneous with respect to the response variable (De'ath & Fabricius, 2000). This analysis can yield a large and complex tree, which produces good predictions on training datasets but poor predictions on validation datasets due to model overfitting (James, Witten, Hastie, & Tibshirani, 2013). In order to overcome this problem, a pruning approach was used in this study to prune the CT into subtrees, the best of which was identified as having the minimum cross-validated error (James et al., 2013).

Observations of trees being removed or retained (n = 6966) were randomly separated into two subsets, training data (70% of observations) and validation data (30% of observations). Fifteen CT models were produced (Table 3.3), which allowed for comparison of the relative importance of resident and household, economic, spatial, and land cover explanatory variables. All analyses were conducted with the statistical software 'R' (R Core Team, 2014). Package rpart (Therneau, Atkinson, & Ripley, 2015) was used to undertake the classification tree analysis, and package rpart.plot (Milborrow, 2016) were used to develop and plot the classification tree.

Table 3.3 – Summary of models for predicting whether trees were removed or retained. See Table 3.2 for detailed descriptions of explanatory variables.

Model Name	**Model Response Variable**	**Model Explanatory Variables**
R	Tree status (removed, retained)	Resident and household variables
E		Economic variables
S		Spatial variables
L		Land cover variables
RE		Resident and household variables and economic variables
RS		Resident and household variables and spatial variables
RL		Resident and household variables and land cover variables
ES		Economic variables and spatial variables
EL		Economic variables and land cover variables
SL		Spatial variables and land cover variables
RES		Resident and household , economic, and spatial variables
REL		Resident and household, economic, and land cover variables
RSL		Resident and household, spatial, and land cover variables
ESL		Economic, spatial, and land cover variables
RESL		Resident and household, economic, spatial, and land cover variables

3.2.2.3.2 Model Validation

In this study, CT models were validated using three metrics (Allouche, Tsoar, & Kadmon, 2006; Cutler et al., 2007; Manel, Williams, & Ormerod, 2001): overall accuracy (ACC) – percentage of trees correctly classified as retained or removed, sensitivity (SN) – percentage of trees correctly classified as retained, and specificity (SP) – percentage of trees correctly classified as removed.

3.3 Results

On the 450 examined residential properties, 6,966 trees were identified in 2011 and 4,544 trees remained by 2015/16 (34.8% removal rate). On the 321 redeveloped residential properties, 4,862 trees existed in 2011 and 2,723 trees remained by 2015/16 (44% removal rate). On the 129 non-redeveloped residential properties, 2,104 trees existed in 2011 and 1,821 trees remained by 2015/16 (13.5% removal rate). On average across all properties, relatively small trees were preferentially removed, while larger trees were retained (Table 3.4). The total canopy cover lost on redeveloped properties (40.2%) was over three times that of non-redeveloped residential properties (12.8%), while the average canopy cover lost on individual redeveloped properties (52.2%) was significantly greater than on non-redeveloped residential properties (18.8%) (Table 3.4).

Table 3.4 – Summary statistics for retained and removed trees on redeveloped and non-redeveloped residential properties. Values were calculated from a combination of delineated crown boundaries and height values derived from the nDSM using the same techniques as Morgenroth et al. (2017). Values shown in bold were significantly different (*p* <0.05) based on a comparison of means using a t-test.

Statistic/Unit	Redeveloped Property	Non-redeveloped Property
Canopy cover lost from all properties (%)	40.2	12.8
Mean (standard error) canopy cover lost per property (%)	**52.2 (1.77)**	**18.8 (2.22)**
Mean (standard error) height of retained trees (m)	**5.8 (0.06)**	**5.3 (0.06)**
Mean (standard error) height of removed trees (m)	5 (0.05)	5.3 (0.13)
Mean (standard error) crown area of retained trees (m^2)	13.6 (0.36)	12.8 (0.51)
Mean (standard error) crown area of removed trees (m^2)	11.6 (0.27)	12.1 (0.66)
Mean (standard error) crown volume of retained trees (m^3)	109.5 (6.17)	98 (7.78)
Mean (standard error) crown volume of removed trees (m^3)	73.2 (2.94)	79.2 (7.93)

3.3.1 Model Performance

A comparison of the fifteen classification trees shows that the best model (overall accuracy = 73.4%) for explaining tree removal and retention was the model including the economic, land cover, and spatial variables as candidate explanatory variables (model ESL) (Table 3.5). Predicting tree retention (sensitivity = 87.85%) was done with a higher level of accuracy than predicting tree removal (specificity = 55.29%). The model only including spatial variables was best for predicting retained trees, while removed trees were most successfully predicted by the model including spatial relationships and land cover variables. In terms of overall accuracy, models with a larger number of variables tended to perform better; models considering only one of residential and household variables, economic variables, or spatial variable sets yielded amongst the poorest accuracies (ACC = 64.84% - 66.53%) (Table 3.5). In contrast, the model considering only land cover variables has a high overall accuracy (ACC = 72.14%).

Table 3.5 – Results of model validation. Bolded text shows the highest values for each validation metric for each model. Abbreviations and descriptions for models are listed in Table 3.3.

CT Model	# of Explanatory Variables	ACC	SN	SP
R	7	64.84%	78.89%	39.15%
E	5	66.25%	86.26%	29.63%
S	3	66.53%	**87.85%**	27.51%
L	12	72.14%	84.74%	49.07%
RE	12	69.38%	83.37%	43.78%
RS	10	66.06%	85.68%	30.16%
RL	19	72.51%	84.38%	50.79%
ES	8	69.28%	85.47%	39.68%
EL	17	72.98%	84.38%	52.12%
SL	15	72.84%	82.43%	**55.29%**
RES	15	67.37%	86.70%	32.01%
REL	24	70.97%	83.22%	48.54%
RSL	22	72.32%	84.74%	49.60%
ESL	20	**73.40%**	83.66%	54.63%
RESL	27	73.35%	83.37%	55.03%

3.3.2 Variable Importance

The best model, ESL, predicted that 70% of trees would be retained and 30% would be removed, while in reality 65% of trees were retained and 35% of trees were removed between the two time periods. The complete classification tree for model ESL had forty-seven nodes and eleven levels (Table 3.6). For simplicity, the classification tree shown in Figure 3.3 is a pruned version of the complete CT. The CT shows that trees that were retained were most likely to be on the properties that were not redeveloped (30%). However, the model also predicted that trees would be retained on redeveloped sites (14%) if those trees were more than 1.4 m from the demolished building and the size of the property exceeded 1,107 m^2. Trees were most likely to be removed if they were on a redeveloped residential property with a capital value less than NZ$1,060,000, within 1.4 m of a demolished building (17%) or if they were on a relatively small redeveloped site, within 10 m of the driveway (15%).

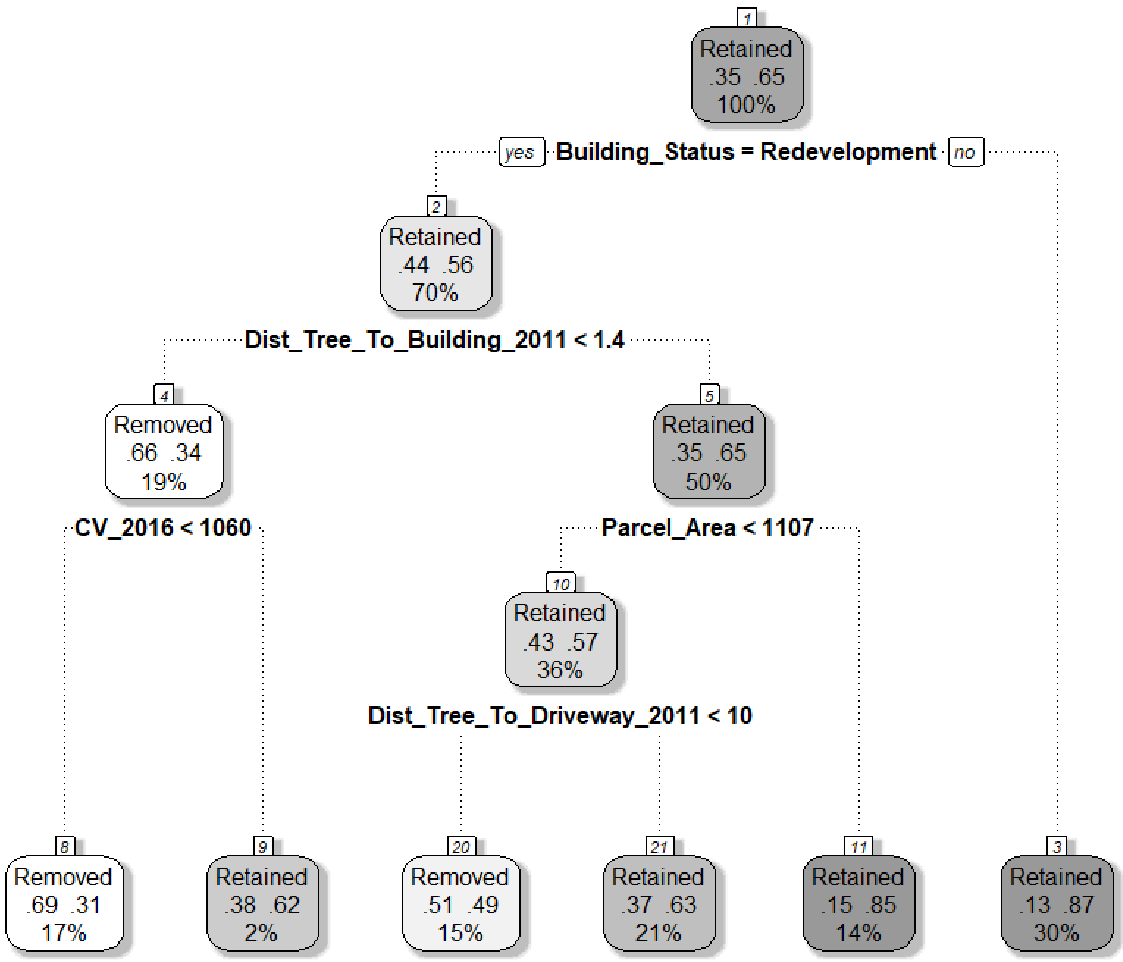

Figure 3.3 – The classification tree for the model with the highest overall accuracy (ESL model). For simplicity, the complete CT was pruned to retain only the top four levels. Descriptions of variables used in the nodes, including units of measure, are found in Table 3.2.

In a classification tree, explanatory variables are selected in order of declining deviance in the response variables (Crawley, 2012). Hence, explanatory variables with a higher position in the classification tree has a greater effect on tree status. In the best model, ESL, in Figure 3.3, building status (Figure 3.3, node 1) was the most important predictor of tree removal and retention. Trees were over three times more likely to be removed on the redeveloped residential properties ($probability_{removed}$(Redevelopment=yes) = 0.44, $probability_{removed}$(Redevelopment=no) = 0.13). The second most important discriminating variable (Figure 3.3, node 2) was the linear distance between a tree crown boundary and a demolished building's boundary. The probability of tree removed was approximately double if a tree was closer than 1.4 m to the boundary of a building ($probability_{removed}$(Dist_Tree_To_Building_2011<1.4m) = 0.66, $probability_{removed}$(Dist_Tree_To_Building_2011≥1.4m) = 0.35). The third most influential variables on tree removal and retention were capital value of properties in 2016 (Figure 3.3, node 4) and property parcel area (Figure 3.3, node 5). Trees on properties with capital values less than NZ$1,060,000 in 2016 ($probability_{removed}$(CV_2016<1060) = 0.69) were over 1.8 times more likely to be removed relative to trees on properties with higher capital value in 2016 ($probability_{removed}$(CV_2016≥1060) = 0.38), while trees on relatively small properties ($probability_{removed}$(Parcel_Area<1107m^2) = 0.43) were approximately three times more likely to be removed compared to larger properties ($probability_{removed}$(Parcel_Area≥1107m^2) = 0.15). The next most important predictor in the classification tree for tree removal and retention was the linear distance between a tree crown boundary and the driveway in 2011 (Figure 3.3, node 10). Tree were removed more frequently when they were within 10 m of the driveway. The remaining predictors for tree removal and retention were relatively less influential than the predictors shown in the Figure 3.3, but are identified in Table 3.6.

3.4 Discussion

3.4.1 Variable Importance in Predicting Tree Removal and Retention

This study found that the model including a variety of economic, spatial, and land cover explanatory variables (model ESL) yielded the highest overall accuracy and, thus, had the best ability to predict both tree removal and retention at a property scale (Table 3.5). In particular, redevelopment status was the most important variable in determining whether trees were removed or retained. These results are in line with previous studies that found urban development and redevelopment are associated with loss of trees (Jim, 1998; Koeser et al., 2013; Nowak & Greenfield, 2012, 2018; Nowak & Walton, 2005). By examining the fate of individual trees and inclusion of trees on both redeveloped and non-redeveloped properties, this study was able to show that not only does tree loss occur during redevelopment, but that trees were over three times as likely to be removed from a redeveloped residential property as compared to a residential property that was not redeveloped. Thus, a much higher rate of tree loss occurred on redeveloped property, with the strongest explanatory factors being the redevelopment itself. The higher rate of tree loss on redeveloped property is possibly because those trees hindered the demolition or construction process during redevelopment, were cleared to make space for the new buildings, or because the redevelopment process provided an opportunity to remove a previously unwanted tree. There is an opportunity for further study to examine the motivations for tree removal.

Table 3.6 – Summary of the complete classification tree of model ESL. See Table 3.2 for detailed descriptions of explanatory variables.

Node	Level	Explanatory Variable	Variable Category	Threshold for Removal
1	1	Building_Status	Land cover variable	Redevelopment = yes
2	2	Dist_Tree_To_Building_2011	Spatial variable	< 1.4 m
4	3	CV_2016	Economic variable	< NZ$1,060,000
5	3	Parcel_Area	Land cover variable	< 1,107 m^2
8	4	Dist_Tree_To_Building_2011	Spatial variable	< 0.18 m
10	4	Dist_Tree_To_Driveway_2011	Spatial variable	< 10 m
17	5	IV_2016	Economic variable	≥ NZ$311,000
20	5	Rd_Area_MB	Land cover variable	≥ 5,654 m^2
21	5	TCC_2011	Land cover variable	< 29%
34	6	TCC_2011	Land cover variable	< 47%
40	6	Rd_Area_MB	Land cover variable	< 11,000 m^2
42	6	IV_2016	Economic variable	≥ NZ$318,000
43	6	Parcel_Area	Land cover variable	< 720 m^2
80	7	NZDep2013_MB	Economic variable	≥ 5.5
81	7	TreeC_2011	Land cover variable	≥ 9 m^2
84	7	LV_2016	Economic variable	< NZ$124,000
86	7	Household_Income	Economic variable	NZ$30,001-70,000 = yes; More than NZ$100,000 = yes
161	8	CV_2016	Economic variable	< NZ$655,000
163	8	Impervious_Cover_2015	Land cover variable	< 64%
169	8	LV_2016	Economic variable	≥ NZ$152,000
338	9	Impervious_Cover_2015	Land cover variable	≥ 60%
676	10	Rd_Area_MB	Land cover variable	< 15,000 m^2
1352	11	Rd_Area_MB	Land cover variable	≥ 8,451 m^2

Land cover (including redevelopment status) and spatial variables best predicted tree removal (highest specificity), while spatial variables alone best predicted tree retention (highest sensitivity). This is an interesting result as all three accuracy metrics agree on the importance of spatial variables in predicting both tree retention and tree removal, but identify different categories of variables as being secondarily important in predicting whether trees were removed and retained (land cover and economics variables, model 'ESL') and tree removal (land cover variables, model 'SL').

The most important spatial variables were tree proximity to a building or driveway; both important predictors for tree removal. In both these scenarios, tree removal was likely influenced by conflicts with demolition or construction activities. This supports previous studies that have stated the significant effects of spatial relationships on tree dynamics (Lavy & Hagelman, 2017; Morgenroth et al., 2017); where the tree is located on the property matters.

Both tree-related and built environment-related land cover variables were identified by the CTs as influencing tree status. The prominent role of land cover explanatory variables in predicting tree status confirms the work of recent research on evaluating tree canopy cover (Lowry Jr et al., 2012; Pham et al., 2013), individual tree loss (Morgenroth et al., 2017; Ossola & Hopton, 2018), and tree species richness (Kendal et al., 2012b). The land cover variables of these studies vary from built environments (e.g. development age, house types) to tree-related attributes (e.g. tree height, crown area). In this analysis, trees on relatively small properties were more likely to be removed than those on larger properties, perhaps because those on larger properties are less likely to conflict with demolition or redevelopment activities.

Previous research has emphasized that tree-related features had effects on tree removal decisions (Hofmann, Gerstenberg, & Gillner, 2017; Morgenroth et al., 2017). This study also found that tree height influenced tree removal and retention. On redeveloped properties, removed trees were shorter and had smaller crown area and volume than retained trees (Table 3.4). This supports the finding of a recent study by Morgenroth et al. (2017) who showed that small trees were preferentially removed during building demolition. In contrast, on the properties that were not redeveloped, the differences of tree-related structural features between retained and removed trees were minor (Table 3.4). A potential explanation for this is that small trees are easier to remove during redevelopment, while removing large trees may require technical support and specialized equipment, adding to the redevelopment costs. Selective removal of small trees on residential properties may have some negative consequences. Because ecosystem services are normally based on tree leaf area (Nowak et al., 2008), small trees generally provide a fraction of the ecosystem services that large trees do; however, from the perspective of biodiversity, removal of small trees may be potentially important. As the private residential gardens in Christchurch, mainly consist of native species (Stewart et al., 2004), removal of small trees likely reduces the tree species diversity of Christchurch's urban forest, resulting in negative ecological consequences.

Economic variables were identified as important in model 'ESL', which yielded the highest overall accuracy for predicting whether trees were removed or retained. Trees on redeveloped residential properties with 2016 capital values of less than NZ$1,060,000 faced a relatively high risk of removal. Given that the mean capital value of properties in this study was NZ$714,000 (Table 3.2), a tree removal threshold of NZ$1.06 million suggests that tree removal was widespread on all but the most expensive properties in the study area. This supports previous research, like that of Grove et al. (2014) who showed that greater tree cover was correlated with properties having a high average capital value. It has to be noted, however, that only 2016 capital values were available for the present study. This reflects the valued of the redeveloped property, rather than the value of the property prior to its redevelopment. Though 2016 CVs are undoubtedly correlated with 2011 CVs, it is possible that not including 2011 capital values prevents a more nuanced understanding of the effects that economic variables have on whether trees are removed or retained during residential property redevelopment. For example, this study could not quantify whether redevelopment significantly increased the value of the property without the 2011 value.

An interesting result is that none of the resident and household variables were identified by the classification tree as influencing tree removal and retention. This may be an artefact of the study design. These data (i.e. gender, age, ethnicity, religion, education) were collected via the mail survey, whereby this study requested that the household's primary decision maker complete the survey. It is possible that the participant was the primary decision maker, but not the person who made decisions regarding tree removal or retention during redevelopment. This result deserves further exploration given that previous studies have generally supported the importance of demographic data for influencing urban forest dynamics (Grove et al., 2006; Krafft & Fryd, 2016; Steenberg et al., 2015), but some finer-scale studies suggest that property characteristics are more important (Pham et al., 2013; Shakeel & Conway, 2014).

3.4.2 Tree and Property-scale versus Broader-scale Explanatory Variables

Interestingly, the classification tree did not identify meshblock scale explanatory variables as having a large impact on tree removal or retention. Perhaps this implies that tree management decisions made at the scale of the individual property are less influenced by factors at a larger scale (in this case, the meshblock scale). Alternatively, perhaps this study did not include all relevant variables at larger scales. A previous study by Bigsby et al. (2014) demonstrated that property-scale factors (e.g. parcel area) and neighbourhood-scale factors (e.g. road density) both have explanatory value to predict corresponding canopy cover, however, fine-scale urban forest characteristics were more related to fine-scale predictors. This agrees with the findings that the property-scale variables were more important predictors for tree removal and retention, relative to meshblock scale variables (e.g. road density).

The importance of property-scale explanatory variables might also indicate the primary role individual households have in private garden management. The majority of urban trees exist in private gardens whose dynamics depend mainly on residents' motivations (Conway, 2016; Shakeel & Conway, 2014). Additional research is necessary to investigate resident's motivations for tree removal or retention during redevelopment.

3.4.3 Canopy Cover versus Individual Tree Dynamics

Previous research has primarily focused on the impact of urban development on tree canopy cover (Bigsby et al., 2014; Brunner & Cozens, 2013; Pauleit et al., 2005), as canopy cover is typically linked with urban ecosystem services and aesthetic value (McPherson et al., 2011). While canopy cover is a useful response variable, it is coarse, and does not provide the same opportunities to understand urban forest dynamics that individual tree removal and retention do. Using individual trees as response variables provides opportunities to understand and explain fine-scale urban forest dynamics (Ossola & Hopton, 2018). The challenge to such studies is accurate tree delineation. In this study, nearly 7000 trees were manually delineated over 450 properties. Applying the same methods city-wide would be impractical. Instead, automated tree delineation would be necessary, though detection accuracies will need to be improved (Holopainen et al., 2013) if automated approaches are to be successful.

A necessary omission from this study is the exclusion of tree planting following redevelopment. Though it would have been interesting to include tree planting, new trees are generally short with small crowns and are not accurately captured by remote sensing data sources, so it was not possible to include tree planting in this study. However, the Christchurch City Council acquires aerial photographs and LiDAR data on a three year cycle, so further research should consider post-redevelopment tree planting and its offsetting effect on the trees removed during redevelopment to better understand if reduced canopy cover is temporary or a more permanent condition.

3.4.4 Management Implications

This study found residential property redevelopment is associated with a much higher loss of trees than those properties that did not undergo redevelopment, making it the most important explanatory variables in predicting residential tree loss in this study. Beyond redevelopment status, other land cover, economic, and spatial variables were more important than resident and household characteristics to predict whether trees were removed or retained on redeveloped properties. This implies that property-scale decisions about tree dynamics are driven less by who the property owner is, and more by the physical characteristics of the property and spatial relationships between trees and other features on the property. These findings have potentially positive implications for managing trees on private properties (Conway & Urbani, 2007; Cooper, 1996; Perkins et al., 2004), as it may be possible to design legislation or policy to protect trees during redevelopment (Despot & Gerhold, 2003). Many cities and countries, including New Zealand, already implement guidelines, best management practice documents (BMPs) or legislation to protect urban trees (British Standards Institution, 2012; Fite & Smiley, 2016; Standards Australia International Ltd, 2009). In New Zealand, a BMP called "A guideline for tree and bush protection on development sites" exists (New Zealand Arboricultural Association, 2011), however it has no legal authority and as such, developers need not adhere to the best practices. Currently, no blanket legal tree protection exists in Christchurch, though a small number (approximately 1,000 trees city wide) are specifically protected as significant trees in the district plan. Other legislation or policy ideas may include replanting when tree removal is unavoidable, specification of minimum permeable areas to remain on redeveloped sites, or specification of minimum distances between buildings and trees.

3.5 Conclusion

Property-scale processes and decisions can cumulatively have effects on broader urban forest patterns. This phenomenon is evident when redevelopment occurs on residential properties. Despite this, little research has explored redevelopment-related influences on urban trees at a property scale. This study analysed the potential for redeveloped and non-redeveloped status, land cover, spatial, economic resident and household, variables to predict tree removal and retention on residential properties in Christchurch, New Zealand.

The classification tree model that included land cover, spatial, and economic variables best predicted tree status. The results indicate that redevelopment of residential properties had significant effects on residential tree removal. On the 450 residential properties examined, trees were over three times as likely to be removed from a redeveloped property relative to a property that was not redeveloped. Other major influencers of tree removal and retention were the distance between a tree crown boundary and the boundary of a redeveloped building or the property's driveway. Trees within 1.4 m of a redeveloped building or within 10 m of a driveway on a redeveloped property were more likely to be removed. These factors suggest that trees are removed to create space during demolition and construction and/or for new buildings' footprint. Property capital value in 2016 and parcel area performed as equally important determinants of tree removal and retention. Trees tended to be removed on redeveloped residential properties with capital values lower than NZ$1,060,000 or parcel areas less than 1,107 m^2. Although this study determined that property-scale tree removal or retention was not affected by household and resident factors, previous research suggests that these factors should not be overlooked. The findings highlight the importance of ensuring appropriate tree protection practices during redevelopment as a strategy to maintain and grow the urban forest.

Chapter 4

The Effects of Property Redevelopment on Resident Attitudes and Actions towards Trees

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4.1 Introduction

Urban forests are increasingly acknowledged as playing an integral role in creating manifold benefits for urban residents (Dwyer, McPherson, Schroeder, & Rowntree, 1992; Mullaney, Lucke, & Trueman, 2015; Roy et al., 2012). Specifically, urban forests provide benefits to residents in three aspects: environment (e.g. improving air quality, providing shade, reducing noise, and ameliorating the urban heat-island effect (Dobbs et al., 2011; Fang & Ling, 2003; McPherson et al., 2011)), social (e.g. reducing stress, providing outdoor leisure opportunities, and stimulating social cohesion (Hazer, Formica, Dieterlen, & Morley, 2018; Tyrväinen et al., 2014; van Dillen, de Vries, Groenewegen, & Spreeuwenberg, 2012)), and economic (e.g. saving cooling and heating costs and increasing property value (Conway & Urbani, 2007; McPherson, Simpson, Peper, Maco, & Xiao, 2005)). Maximising these benefits requires that attention be given to the influence of humans on urban forests (Dilley & Wolf, 2013) as people can indirectly and directly impact trees, both positively (De Sousa, 2003; Doody, Sullivan, Meurk, Stewart, & Perkins, 2010; Jim, 2004) and negatively (Bagnall, 1979; Morgenroth, Santos, & Cadwallader, 2015; Richardson & Shackleton, 2014).

The structure, composition and extent of urban forests are temporally dynamic. Within many western cities, a large proportion of trees are located on private land (Pearce et al., 2013), and managed by private landowners and managers. For example, in Christchurch, New Zealand, where the present study was conducted, 75% of urban trees are located on private land (Morgenroth, 2017), suggesting that in this city there are tens of thousands of individuals managing trees on their private properties. A consequence of land ownership is that individual values and attitudes towards trees impact fine-scale urban tree management on and around private land and thus, cumulatively, affect urban forest dynamics (Cook, Hall, & Larson, 2012; Visscher, Nassauer, & Marshall, 2016).

The concept of value in relation to urban trees can be generally refer to how people assign importance and meanings to urban trees (Ives & Kendal, 2014; Peckham, Duinker, & Ordóñez, 2013). Value is associated with individual emotions and cognitions that have the potential to predict attitudes and preferences towards urban trees (Ordóñez, 2017). Previous studies have increasingly given attention to resident attitudes towards urban trees (e.g. Avolio et al. 2015; Lohr, Pearson-Mims, Tarnai, and Dillman 2004; Vesely 2007). Other studies have shown that attitudes and actions towards urban trees can be affected by socio-economic characteristics. For example, residents with relatively high income and education levels are more likely to support urban forest policies and engage in urban forest management (Conway & Bang, 2014; Kirkpatrick et al., 2011; Zhang, Hussain, Deng, & Letson, 2007; Zhang & Zheng, 2011). Ethno-cultural diversity has also been shown to be an important mechanism of varied resident attitudes towards trees (Fraser & Kenney, 2000), and thus it too can affect tree planting and removal (Ordóñez, 2017). Other socio-economic variables, such as house tenure, age, and employment, can also influence tree-related decisions in the context of urban development (Kirkpatrick et al., 2011).Meanwhile, resident values and attitudes towards urban trees guide their tree management actions (Ives & Kendal, 2014). Studies have shown that residents planting trees in private gardens typically give priority to valued ecosystem services (e.g. aesthetics, shading, and energy saving) provided by trees, while removing trees is largely attributed to perceived nuisances or disservices associated with trees (e.g. poor tree health conditions, overgrowth, and messiness) (Conway, 2016; Kirkpatrick et al., 2012; Summit & McPherson, 1998).

Recent research has also explored urban forest dynamics associated with property-scale construction activities such as building demolition (Morgenroth et al., 2017), renovation (Steenberg et al., 2018), and redevelopment (Guo, Morgenroth, & Conway, 2018). These studies have shown that construction activities on properties often result in tree removal. While previous studies have explained some of the nuance in the relationship between construction activities and tree removal (e.g. preferential removal of small trees in close proximity to buildings (Guo et al., 2018; Morgenroth et al., 2017)), a critical factor has been overlooked. Little research has considered landowners' attitudes towards trees (e.g. belief they are a nuisance, or find them aesthetically pleasing and beneficial) in the context of house construction (though exceptions exist, e.g. O'Herrin, Hauer, Vander Weit, and Miller, 2016), which is problematic given that tree-related decision making is made by the property owner (Shakeel & Conway, 2014). Establishing the link between resident attitudes and their actions towards trees (e.g. removal, maintenance, planting) during property redevelopment is key to further develop a more complete understanding of urban forest dynamics.

This study explores the relationship between resident attitudes and actions towards trees on property undergoing substantial ongoing redevelopment. Specifically, this research explores: 1) rates of tree removal, retention, and planting on residential properties; 2) residents' attitudes towards trees; and 3) whether resident attitudes or their actions towards trees differed on redeveloped versus non-redeveloped properties.

4.2 Methods

4.2.1 Study Area

This study was conducted in Christchurch, located on the east coast of the South Island of New Zealand (Lat: 43.5321° S, Long: 172.6362° E) (Figure 4.1). Christchurch is New Zealand's third largest city with a 2013 population of 341,469 (Statistics New Zealand, 2014). Twenty-two percent of the population in Christchurch was born overseas, and the city contains a diverse ethnicity that is mainly comprised of European (84%), Asian (9%), Māori (9%), and Pacific peoples (3%) (Statistics New Zealand, 2014). Data derived from the 2013 New Zealand Census indicate that 21% of people in Christchurch hold a Bachelor's degree or higher as their highest educational qualification, and the median household income was NZ$65,300 compared to the national median income of NZ$63,800.

Christchurch is known as 'The Garden City' owing to numerous public gardens and green spaces. Urban forest canopy cover in Christchurch is approximately 16% ranging from 7% to 29% in different political wards (Morgenroth, 2017). Public parklands are mainly covered by exotic tree species and shrubs, while native tree species are commonly located in residential gardens (Stewart et al., 2009).

In 2010 – 2011, the Canterbury Earthquake Sequence (CES) impacted Christchurch (Quigley et al., 2016), causing damage to thousands of dwellings and rendering them uninhabitable (Christchurch City Council, 2015). The total number of occupied dwellings decreased from 135,270 in 2006 to 131,007 in 2013 (Statistics New Zealand, 2014). After the CES, redevelopment of damaged properties began and as of 2018 was still ongoing. These redeveloped properties, along with corresponding non-redeveloped properties formed the initial population of properties to be considered for inclusion in this research.

A mail-based questionnaire was sent to redeveloped and non-redeveloped properties using the following procedure. A list of Code of Compliance Certificates (CoCC) was used to identify potentially redeveloped residential properties. A CoCC is issued by the Christchurch City Council to property owners that have completed their development and met all conditions of their building consent. It signifies the legal completion of a property's redevelopment. While the CoCC list contained all completely redeveloped properties (e.g. previous dwelling completely demolished and new dwelling constructed), it also included properties that underwent less significant forms of consented development (e.g. building roof repair, deck alteration, and structural strengthening). Thus, all properties on the CoCC list were visually assessed using aerial photographs from 2011 and 2015/16 to verify and identify redeveloped residential properties (Appendix D). Only 1,956 residential properties that had clearly been completely redeveloped were included for further study. Obvious signs of complete redevelopment included change of building footprint or change in building position within a property.

As an experimental control, a questionnaire was also sent to land owners of residential properties that had not been redeveloped. For each redeveloped residential property, a non-redeveloped control property was randomly selected from adjacent properties. If all bordering properties had also been redeveloped, the nearest non-redeveloped residential property (straight line distance between geometric centres of the redeveloped and non-redeveloped property) within the same meshblock was selected. In total, 3,912 questionnaires were mailed out, half to redeveloped properties, and half to non-redeveloped properties (Figure 4.1).

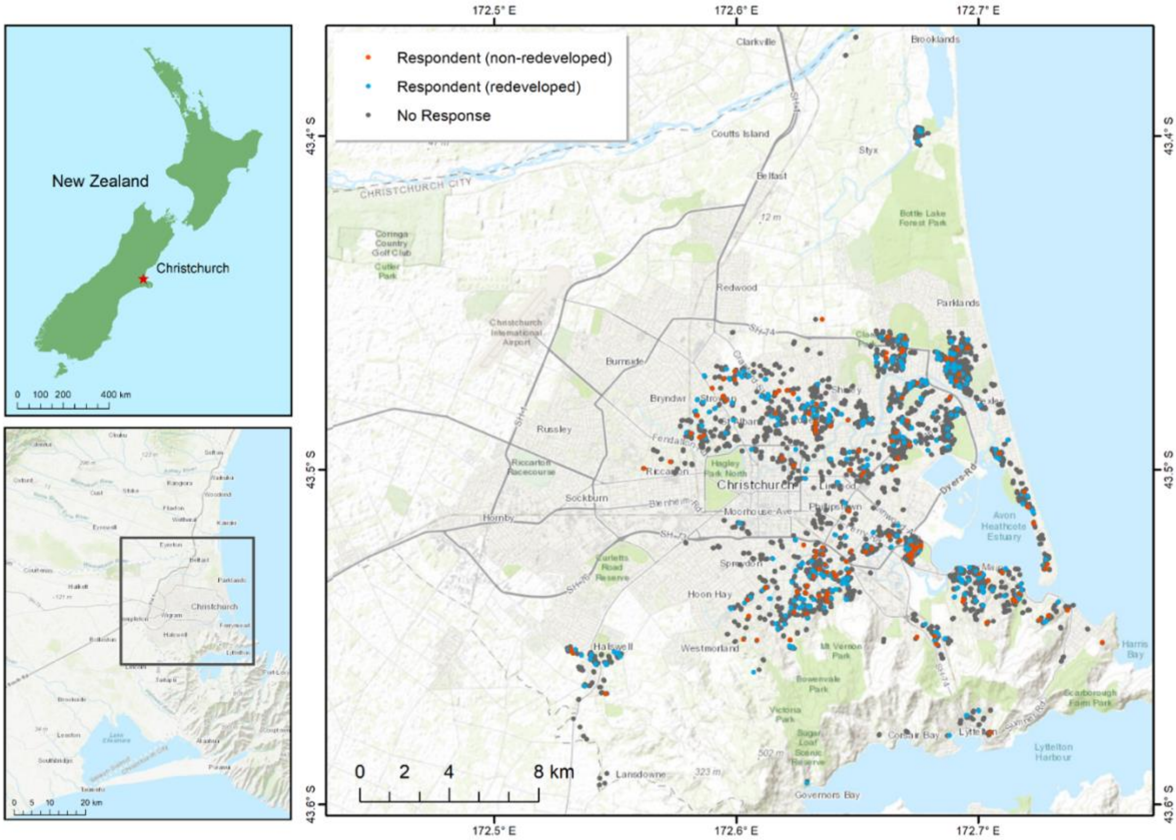

Figure 4.1 – Distribution of individual residential properties included in the study. Grey dots represent the properties that questionnaires were mailed to but were not returned; orange dots represent the properties that were not redeveloped whose returned questionnaires were used in the study; blue dots represent the redeveloped properties whose returned questionnaires were used in the study.

4.2.2 Questionnaire

To collect information about resident attitudes towards tree management actions and resident socio-demographics, questionnaires were mailed to the 3,912 residential properties between October 2016 and January 2017 (Figure 4.1), no follow-up contact was conducted. The content of the questionnaire and the method of questionnaire distribution and collection were approved by the Human Ethics Committee of the corresponding author's university. An information sheet included with the questionnaire explained that participants' responses would be used to understand decision-making about trees during property redevelopment. As properties may have more than one occupant, the information sheet explained that the ideal questionnaire respondent was the occupant who is the primary decision-maker. Postage paid envelopes were provided for respondents to mail back their questionnaires. The questionnaires were distributed in English because 97% of residents living in Christchurch speak English (Statistics New Zealand, 2014).

The questionnaire comprised three sections (Appendix C). The first section asked participants about residency information, including whether participants were living at their address during the 2010 – 2011 CES and if their properties had been demolished and rebuilt after the earthquakes. The second section contained a series of binary questions investigating tree management actions (Table 4.1) and corresponding attitudes towards tree removal, retention, and planting. If at least one tree was removed, retained, or planted, then the respondent was asked to indicate the reason(s) for that action from pre-defined lists that were compiled from the scientific literature (e.g. Avolio et al., 2015; Conway, 2016; Kirkpatrick et al., 2012). Thus, attitudes about specific trees on the respondents' property were collected. This approach was used in the present study, as previous work has found that people often express positive attitudes towards trees in general, but have more nuanced attitudes when asked about specific trees (e.g. trees on their own properties) (Conway, 2016). The final section of the questionnaire asked participants to provide socio-demographic information, including gender, age, ethnicity, religion, education level, and annual household income, which have been shown to be associated with urban forest structure and distribution in previous studies (Avolio et al., 2015; Fan et al., 2019; Jim, 2005; Kuhns, Bragg, & Blahna, 2002; Ordóñez, 2017). This section was designed to use questions and categories that were aligned with those asked in the 2013 New Zealand Census (Statistics New Zealand, 2013), such that respondent profiles could be compared with census data from Christchurch (and New Zealand) (Table 4.2); this would allow determination of whether results could be generalised to all of Christchurch.

Table 4.1 – Explanation of tree management actions in questionnaire.

Tree management action	Description
Tree removal	At least one tree that was on the property prior to the 2010 – 2011 CES is no longer on the property.
Tree retention	At least one tree that was on the property prior to the 2010 – 2011 CES remains on the property now.
Tree planting	At least one tree has been planted on the property the after 2010 – 2011 CES.

4.2.3 Statistical Analysis

With a view toward understanding residents' roles in urban forest dynamics, residents' attitudes and actions towards trees during redevelopment were explored. A potential determinant (i.e. property redevelopment status) of those attitudes and actions was also examined. The statistical analyses used in this study were designed based on previous research exploring urban residents' attitudes towards urban forests (Almas & Conway, 2017; Jennings et al., 2016; Kendal, Williams, & Williams, 2012a).

Firstly, questionnaire data were categorised into early-respondent data and late-respondent data for a non-response bias analysis to evaluate whether significant differences existed between respondents and non-respondents. Then, descriptive statistics and chi-square tests were used to examine significant differences in tree management actions and attitudinal statements related to tree removal, tree retention, and tree planting between respondents from redeveloped and non-redeveloped properties. Lastly, principle component analysis (PCA) was conducted to determine if discrete patterns existed among respondents' attitudes towards tree removal, tree retention, and tree planting, respectively. Data were confirmed to meet all statistical assumptions for PCA. Principal components (PCs) with eigenvalues greater than 1 were retained (Kim & Mueller, 1978), and used to represent different dimensions of residents' attitudes towards each tree management action.

4.3 Results

Out of the 3,912 possible respondents, 814 questionnaires were returned (response rate = 21%). However, of these, only 445 (11%) (Figure 4.1) were used in this study. The remaining returned questionnaires (n = 369) were excluded because participants did not answer all of the questions, did not live at the property during the 2010 – 2011 CES, or did not have any trees on their properties. Results from the non-response bias analysis indicated that no statistically significant difference existed in questionnaire data from respondents and non-respondents. Of the 445 questionnaire respondents, 71% of respondents were living at properties that had been redeveloped since the 2010 – 2011 CES, while 29% were living at non-redeveloped properties (Table 4.2).

In comparison to the results of the 2013 Census for Christchurch, the respondents of the questionnaire were older, predominantly female, less ethnically diverse, more religious, better educated, and wealthier (Table 4.2). The vast majority (90%) of respondents were 45 years or older, 61% were female, and 90% identified their ethnicity as New Zealand European. Also, 60% of respondents indicated that they were religious, while more than one third of respondents held a Bachelor's degree or post-graduate (e.g. Master's or PhD) degree. Approximately two thirds of respondents indicated that their annual household incomes exceeded NZ$70,001.

Table 4.2 – Socio-demographic characteristics of respondents and their property status based on questionnaires (n = 445).

Question	Level	Respondent (%)		2013 New Zealand Census Data[1] (%)		
		Redeveloped (n = 317)	Not Redeveloped (n = 128)	Study Area	Christchurch City	New Zealand
Gender	Male	39	39	49	49	49
	Female	61	61	51	51	51
Age	Under 45	9	9	56	59	60
	45-65	46	50	29	26	26
	Over 65	44	41	15	15	14
Ethnicity[2]	New Zealand European	91	87	90	84	74
	Asian	1	0	4	9	12
	Māori	2	3	9	9	15
	Pacific Island	1	0	3	3	7
	Other	5	1	3	3	3
Religion[3]	No Religion	38	46	48	42	42
	Christian	60	52	46	44	49
	Other	2	2	3	4	8
Education Level	None	10	10	18	20	21
	Secondary School Qualification	20	27	38	40	40
	Diploma or Certificate	32	28	21	20	19
	Bachelor's Degree	26	14	15	14	14
	Post-graduate Degree	12	21	8	7	6
Annual Household Income (NZ$)	30,000 or Less	15	16	18	21	22
	30,001-70,000	19	31	32	32	32
	70,001-100,000	30	14	19	19	18
	100,001 or More	36	38	30	28	28

1. Data derived from 2013 New Zealand Census (Statistics New Zealand, 2014).
2. Data included those people who stated they belong to more than one ethnicity.
3. 2013 Census data excluded object to answering, don't know, religion unidentifiable, response outside scope and not stated.

4.3.1 Tree Management Actions

In general, respondents who were living at a redeveloped property engaged in more tree management actions than those who were living at a property that was not redeveloped (Table 4.3). Specifically, 87% of respondents who were living at a redeveloped property reported that at least one tree had been removed after the 2010 – 2011 CES, while 76% reported that at least one tree had been planted after 2010 – 2011 CES. The removal and planting rates for respondents who were living on non-redeveloped properties were much lower – 63% and 46%, respectively. Respondents on redeveloped properties had a greater tendency to undertake tree removal and planting together (68%), while removal and planting on non-redeveloped properties mainly occurred as isolated activities (removal and planting = 38%). While planting rates were lower on non-redeveloped properties, tree retention rates were greater, with 94% of respondents retaining at least one tree. This is in contrast to only 85% of respondents retaining at least one tree on redeveloped properties.

Table 4.3 – Summary of tree management actions after 2010 – 2011 CES. Significant differences ($p < 0.05$) were identified in each tree management action (listed below) between redeveloped and non-redeveloped properties.

Property Status	**Removal (%)**	**Retention (%)**	**Planting (%)**	**Removal and Planting (%)**
Redevelopment (n = 317)	87	85	76	68
Non-redevelopment (n = 128)	63	94	46	38
Overall (n = 445)	80	88	68	59

4.3.2 Resident Attitudes towards Tree Removal, Retention, and Planting

4.3.2.1 Tree Removal

The reasons for tree removal on properties were varied (Table 4.4), though ‘Trees were in the way of demolition or construction vehicles or equipment’ was a common reason identified by 68% of questionnaire respondents. The next most common reason, given by 51% of landowners was that ‘Trees were removed to make space for the new development’. ‘Trees were damaged, diseased or dead’ was also identified as an important reason, with 35% of respondents providing that answer. The next five most cited reasons for tree removal were all identified by less than 10% of respondents and included ‘Tree roots damage drains, foundation or hard landscaping’, ‘Trees shade my garden’, ‘Trees drop messy leaves, flowers, fruit or branches’, ‘Trees shade my house’, and ‘Trees interfere with underground or aboveground services’.

Table 4.4 also shows the significant disparity in responses between landowners living at redeveloped properties and those living at properties that were not redeveloped. Trees had 4.2 and 4.5 times greater chance of being removed by respondents living at redeveloped properties because trees were in conflict with demolition or construction equipment and to make space for new development, respectively. In contrast, on non-redeveloped properties, trees had greater chance of being removed because they were damaged, diseased, or dead (2.1 times greater chance), or because they shaded a garden (3.2 times greater chance) or house (2.7 times greater chance).

Table 4.4 – The reasons provided by landowners for removing trees on their property (n = 356). A correlation for principle loadings above 0.6 was identified as important and were bolded in the table. A star (*) was used to identify the statistically significant differences ($p < 0.05$) in the reasons given for tree removal between redeveloped and non-redeveloped properties.

Reason	**Overall (%)**	**Property Status (%)**		**$PC_{Removal}$ 1**	**$PC_{Removal}$ 2**	**$PC_{Removal}$ 3**
		Redeveloped	**Not Redeveloped**	**Ecosystem disservices**	**Development issues**	**Health conditions**
Trees were in the way of demolition or construction vehicles or equipment*	68	83	20	0.080	**0.727**	0.263
Trees were removed to make space for the new development*	51	62	14	-0.003	**0.720**	0.168
Trees were damaged, diseased or dead*	35	28	58	-0.109	-0.175	**0.726**
Tree roots damage drains, foundation or hard landscaping	10	9	12	0.472	0.180	0.143
Trees shade my garden*	9	6	19	0.521	-0.302	0.053
Trees drop messy leaves, flowers, fruit or branches	9	8	11	**0.649**	-0.067	0.079
Trees shade my house*	8	6	16	**0.687**	-0.212	-0.087
Trees interfere with underground or aboveground services	5	5	6	0.473	0.350	0.041
Trees were exotic or invasive species	5	4	7	0.281	-0.179	0.212
Trees obscure my view	4	4	5	0.305	0.026	0.171
Trees require too much maintenance	4	3	6	**0.645**	-0.004	-0.169
Trees cause allergies or health problems	2	2	3	0.137	-0.237	0.479
Trees promote criminal activities	1	1	0	0.469	0.263	-0.258
Trees attract unwanted animals or insects	1	0	1	0.115	-0.213	0.037
Eigenvalues				2.470	1.576	1.064
Variance Explained (%)				17.643	11.255	7.600

For the resident attitudinal statements related to tree removal, the PCA explained 36.5% of the total variance and three principle components (PCs) were retained (Table 4.4). 17.6% variance was explained by $PC_{Removal}$ 1 (ecosystem disservices) that was associated with statements about trees shading houses, dropping litter, and requiring maintenance. $PC_{Removal}$ 2 (development issues) explained 11.3% of variance and represented statements that were related to obstructing demolition or construction processes and making space for new development. The statement associated with poor tree health conditions was represented in $PC_{Removal}$ 3 (health conditions) that explained 7.6% of variance.

4.3.2.2 Tree Retention

The reasons for retaining trees on a property are summarised in Table 4.5. The top three most important reasons for retaining trees were agreed to by more than 75% of respondents, namely ‘Trees are aesthetically pleasing’ (89%), ‘Trees provide habitat for birds’ (81%), and ‘Trees provide privacy’ (76%). These reasons were followed by ‘Trees provide shade’ (69%) and ‘Trees improve air quality’ (58%). Other reasons including ‘Trees provide habitat for bees’, ‘Trees provide fruit or nuts’, ‘Trees increase property value’, ‘Trees stabilize the soil’, and ‘Trees reduce noise’ were identified by 41-54% of landowners as important reasons to retain trees on their properties. There were no statistically significant differences in the reasons given for tree retention between respondents from redeveloped versus non-redeveloped properties.

PCA for resident attitudes towards tree retention explained 43.71% of total variance and produced three PCs (Table 4.5). $PC_{Retention}$ 1 (ecosystem services) had a stronger explanatory power (variance explained = 31.03%) relative to $PC_{Retention}$ 2 (removal costs) and $PC_{Retention}$ 3 (protection regulation) whose explained variances were 6.61% and 6.07%, respectively. $PC_{Retention}$ 1 represented preferences for the manifold benefits provided by trees. $PC_{Retention}$ 2 was associated with high costs of tree removal. $PC_{Retention}$ 3 was mostly related to government regulation for preventing tree removal with the highest positive value, but highly and negatively related to the statement about future tree removal plans.

Table 4.5 – The reasons provided by landowners for retaining trees on their property (n = 392). A correlation for principle loadings above 0.6 or below -0.6 was identified as important and were bolded in the table.

Reason	**Overall (%)**	**Property Status (%)**		**$PC_{Retention}$ 1**	**$PC_{Retention}$ 2**	**$PC_{Retention}$ 3**
		Redeveloped	**Not Redeveloped**	**Ecosystem services**	**Removal costs**	**Protection regulation**
Trees are aesthetically pleasing	89	89	90	**0.633**	0.132	-0.050
Trees provide habitat for birds	81	79	86	**0.733**	0.038	-0.066
Trees provide privacy	76	76	76	**0.652**	0.219	0.010
Trees provide shade	70	69	70	**0.661**	0.101	0.114
Trees improve air quality	58	59	57	**0.734**	-0.001	-0.014
Trees provide habitat for bees	54	54	56	**0.661**	-0.126	-0.147
Trees provide fruit or nuts	48	47	52	0.504	-0.232	-0.050
Trees increase property value	48	50	43	**0.614**	0.027	-0.124
Trees stabilize the soil	45	44	46	**0.642**	-0.020	-0.050
Trees reduce noise	41	41	41	**0.679**	-0.025	0.043
Trees are native species	32	31	35	0.461	0.005	0.333
Trees are culturally important	24	23	28	0.523	-0.236	0.094
Trees celebrate a person or pet	17	17	16	0.480	-0.191	-0.180
Trees provide recreation potential	16	16	16	0.524	-0.103	0.070
Trees reduce heating or cooling costs	11	12	8	0.500	-0.121	-0.020
High costs for removal	7	6	9	0.210	**0.666**	-0.100
Government regulation prevents tree removal	3	2	4	0.147	0.509	**0.655**
Have not yet had time to remove	2	2	3	0.013	0.469	**-0.657**
Eigenvalues				5.586	1.190	1.093
Variance Explained (%)				31.031	6.611	6.071

4.3.2.3 Tree Planting

The most common reason people chose for planting trees on their properties was that ‘Trees are aesthetically pleasing’; 81% of respondents chose this option (Table 4.6). The second and third most common reasons were ‘Trees provide habitat for birds’ (61%) and ‘Trees provide privacy’ (60%). Other reasons with response rates between 34-55% include ‘Trees provide fruit or nuts’, , ‘To replace removed tree(s)', 'Trees provide shade', 'Trees provide habitat for bees', 'Trees increase property value', 'Trees improve air quality', and 'Trees stabilize the soil'.

Two reasons were identified as significantly different among respondents from redeveloped and non-redeveloped properties. Specifically, respondents from redeveloped properties were more likely to cite 'To replace removed tree(s)' (2.3 times greater chance) and 'Trees are aesthetically pleasing' (1.2 times greater chance) as their reason for tree planting, relative to respondents from non-redeveloped properties.

Table 4.6 – The reasons provided by landowners for planting trees on their property (n = 301). A correlation for principle loadings above 0.6 was identified important and were in bold in the table. A star (*) was used to identify the statistically significant difference ($p < 0.05$) in the reason between redeveloped and non-redeveloped property status.

Reason	Overall (%)	Property Status (%)		$PC_{Planting}$ 1
		Redeveloped	Not Redeveloped	Ecosystem services
Trees are aesthetically pleasing*	81	84	68	**0.726**
Trees provide habitat for birds	61	61	61	**0.823**
Trees provide privacy	61	62	56	**0.761**
Trees provide fruit or nuts	55	53	61	0.508
To replace removed tree(s)*	49	55	24	0.493
Trees provide shade	49	50	42	**0.754**
Trees provide habitat for bees	48	48	48	**0.751**
Trees increase property value	48	50	37	**0.673**
Trees improve air quality	43	44	39	**0.783**
Trees stabilize the soil	34	34	32	**0.694**
Trees reduce noise	30	30	29	**0.737**
Trees are culturally important	18	18	17	0.584
Trees celebrate a person or pet	12	13	10	0.467
Trees provide recreation potential	10	10	14	0.549
Trees reduce heating or cooling costs	9	10	7	0.520
Eigenvalues				6.640
Variance Explained (%)				44.270

Only one PC, $PC_{Planting}$ 1 (ecosystem services), was extracted from PCA for resident attitudes towards tree planting (Table 4.6). $PC_{Planting}$ 1 mostly captures the attitude that trees provide beneficial ecological, social, and economic ecosystem services and explained 44.3% of total variance.

4.4 Discussion

The results provide a better understanding of the link between resident attitudes and their actions towards trees in Christchurch, New Zealand. The results highlight that residents from both redeveloped and non-redeveloped properties engage in tree removal, retention, and planting, but the rationales for each action are diverse and, in some cases, significantly different. While some resident attitudes towards tree removal vary based on whether or not their property has undergone recent redevelopment, resident attitudes towards tree retention and planting are largely similar, with some exceptions. The results show that respondents from redeveloped properties were more likely to engage in tree removal and planting, while respondents from non-redeveloped properties were more likely to retain trees on their properties over the 5-year period examined in the study (Table 4.3). These results can be explained by the differences in attitudes towards trees between respondents from redeveloped and non-redeveloped properties; these are detailed in the following section.

4.4.1 Reasons for Tree Management Actions

Development-related factors (i.e. ‘Trees were in the way of demolition or construction vehicles or equipment’ and ‘Trees were removed to make space for the new development’) were cited as the most common reasons for tree removal by respondents. This supports previous research that has suggested (Morgenroth & Armstrong, 2012) and measured (Guo et al., 2018; Morgenroth et al., 2017) the link between redevelopment and tree removal in Christchurch. Both reasons were disproportionately associated with redeveloped properties, an obvious, but important result. Previous research has shown that during property redevelopment, individual trees are often removed, which contributes to urban forest degradation in Christchurch (Guo et al., 2018; Morgenroth et al., 2017). In general, the benefits provided by trees may get overlooked in favour of desired development outcomes (Hassan & Lee, 2015). This has also been shown to be true in Los Angeles where redevelopment of single-unit houses has to increased building footprints and decreased tree canopy cover (Lee et al., 2017).

While development-related reasons were most often reported on redeveloped properties, nearly all other reasons for tree removal were reported by a larger proportion of respondents on non-redeveloped properties. Chief amongst them were tree health conditions and associated ecosystem disservices. Approximately one third of respondents (35%) cited poor tree health conditions as the reason for tree removal. Evidently, this response was driven by resident concerns about potential risks (e.g. dropping branches) more common in diseased or older trees (Conway, 2016; Kirkpatrick et al., 2012). An interesting disparity is that 58% of respondents on non-redeveloped properties cited tree health concerns as a reason for removal, but only 28% of respondents on redeveloped properties noted the same reason. This suggests that many of the trees removed from redeveloped properties were in good health and were only removed to make way for development.

Notwithstanding the fact that the scientific literature has historically had a bias towards reporting the benefits of urban forests (see an exception conducted by Lyytimäki and Sipilä (2009)), the respondents in this study were acutely aware of the negative factors (e.g. shade, leaf litter) associated with urban trees and their negative influence on urban human comfort. While residents identified numerous ecosystem disservices, the principle component analysis grouped concerns related to trees shading houses, trees requiring too much maintenance, and trees dropping too much litter as correlated concerns. As in previous studies (Conway, 2016; Kirkpatrick et al., 2012), it appears that specific ecosystem disservices have relatively minor effects on resident decisions about tree removal, with fewer than 10% of respondents citing each reason.

The top three reasons provided by respondents for retaining and planting trees were that trees were aesthetically pleasing, trees provided habitat for birds, and trees provided privacy for properties. Resident focus on the aesthetic value of urban forests is supported by previous studies conducted in Sacramento and Los Angeles, USA (Avolio et al., 2015; Summit & McPherson, 1998), Sydney and Wollongong, Australia (Head & Muir, 2005), and Guangzhou and Hong Kong, China (Jim & Chen, 2006; Lo & Jim, 2012). This study found respondents from redeveloped properties more frequently expressed a positive attitude towards tree aesthetics as the reason for tree planting relative to those from non-redeveloped properties. A possible explanation is that residents whose properties were redeveloped may rely on trees to soften the new built environments.

The common motivation for tree planting for habitat provision, found in this study, supports previous research conducted in eastern Australian cities by Kirkpatrick et al. (2012), while some studies conducted in North American cities suggest that residents give relatively lower priority to tree planting for wildlife (e.g. Lohr et al. 2004; Summit and McPherson 1998). This implies caution is needed when comparing resident attitudes towards tree management actions in different locations, as tree-related preferences may be affected by local customs or ethno-cultural diversity. For example, while it is not common to plant trees in front gardens to enhance privacy in many American cities (Grampp, 2008), a previous Australian study highlighted the preference for tree planting because of privacy provision (Kirkpatrick et al., 2012).

Providing shade is another important functional benefit of trees acknowledged by residents in several other studies (Lohr et al., 2004; Summit & McPherson, 1998), although this too appears to vary by country (Schroeder, Flannigan, & Coles, 2006). In this study, provision of shade was ranked by 76% of residents as a strong reason for tree retention, while less than 50% residents cited shade provided by trees as an important reason for tree planting. This suggests respondents are aware that shade provision is primarily associated with larger, established trees, rather than new plantings. Beyond shade, the reasons cited by respondents for retaining existing trees and planting new trees were similar and centred on ecosystem services provided by trees. This implies that ecosystem services of urban trees should continue to be touted as reasons to not only plant more trees but also to encourage protection of existing trees.

This study showed that many residents have positive attitudes towards the ecosystem services provided by trees, expressed through reasons for retaining and planting trees. But, these attitudes appear secondary to construction-related logistical and cost concerns, given the relatively high percentage of trees removed on redeveloped properties and rationales provided for those removals. These results are aligned with more general findings that residents' pro-environmental attitudes may not correlate with pro-environmental actions on their property (Larson, Cook, Strawhacker, & Hall, 2010), and more specific findings that tree species selection decisions by residents are primarily based on logistical and costs considerations, rather than stated attitudes towards trees (Almas & Conway, 2018). Thus, residents valuing trees for their ecosystem services is not sufficient to ensure trees will be protected during property redevelopment.

4.4.2 Management Implications

This study adds to recent literature that has suggested a relationship between urban forest degradation and redevelopment (Guo et al., 2018; Morgenroth et al., 2017). In spite of this recent research, redevelopment need not have negative impacts on urban forests. There are numerous examples in Christchurch where redevelopment sensitively incorporated existing trees and even increased canopy cover with tree planting following construction. Urban forest managers and policy makers have an opportunity to work with stakeholders (e.g. landowners and developers) to ensure redevelopment is undertaken with minimal negative (or even positive) impact on the urban forest. Doing so can help ensure residents benefit from the associated ecosystem services.

For example, the reasons cited by respondents for retaining existing trees and planting new trees were similar and centred on ecosystem services provided by trees. This implies that ecosystem services of urban trees should continue to be touted as reasons to not only plant more trees, but also to encourage protection of existing trees.

Interestingly, the high cost of removal and perceived or actual government regulation preventing tree removal were identified by 7% and 3% of respondents respectively. While these are not large proportions, they highlight factors that can influence tree removal action. Those mechanisms in relation to government regulation could play important roles in helping cities reach or maintain urban forest canopy cover goals. For example, several previous studies have found positive outcomes when government regulations include financial penalties for private tree removal (Conway & Urbani, 2007; Cooper, 1996; Hill et al., 2010; Landry & Pu, 2010; Sung, 2012).

Redevelopment provides an opportunity for landowners to redesign their private garden landscape, and many landowners is this study planted new trees. However, previous studies have suggested that residents often have limited knowledge about tree species (Shackleton & Shackleton, 2016; Verbrugge, Born, & Lenders, 2013). This is an opportunity for urban foresters to prepare tree species lists to advise landowners about the most suitable trees for their garden and neighbourhood (Wyse, Beggs, Burns, & Stanley, 2015). Meanwhile, builders and landscapers, who play direct roles in property redevelopment, should receive training about tree protection methods, which could help minimise the negative effects of redevelopment on *in situ* trees.

Incidentally, New Zealand does have a guideline for tree and bush protection on development sites (New Zealand Arboricultural Association, 2011), but the guideline has no legal authority. Christchurch also has a small number of legally protected notable trees (old, large, or culturally important trees), identified in its district plan, however, this mechanism for tree protection is not fit-for-purpose with respect to non-notable landscape trees. Instead, specific legislation or bylaws could be designed to provide incentives or assess penalties to prevent tree removal (Despot & Gerhold, 2003). Moreover, the results show that the amount of tree removal exceeds that of tree planting during redevelopment. As such, in addition to tree protection policy, legislation could also be mandated to require replanting to offset the negative effects of tree removal caused by redevelopment.

4.4.3 Limitations of the Study

The response rate in this study, 21% of 3,912 possible respondents, was lower than comparable studies conducted by Conway (2016) (response rate = 43%) and Larson et al. (2010) (response rate = 38%). Multi-contact or face-to-face invitations may have increased the response rate (Dillman, Smyth, & Christian, 2014; Kirkpatrick et al., 2012). Given that previous research has shown that questionnaires distributed in multiple languages have a higher response rate (e.g. Balram and Dragićević 2005), future studies should consider multiple versions in different languages when conducting questionnaires in multicultural cities.

Moreover, while completing the 2013 census was required by law (under the Statistics Act 1975), responding to the survey was voluntary. This could explain the relatively low response rate, but also why the respondent profile differed markedly from the profile of a typical resident of Christchurch, based on the 2013 census data (Table 4.2), with questionnaire respondents being older, predominantly female, less ethnically diverse, more religious, better educated, and wealthier. As such, it is possible that the results are not generalisable to all of Christchurch. Despite this, the respondent profile is of interest. This study requested that the ideal survey participant be the person in the household that is the primary decision maker. Since 61% of the respondents were female, this implies that perhaps the primary decision makers in managing urban forests are female. This is a clear area for further research.

It is unlikely that a greater response rate would have yielded more generalisable results, because questionnaire recipients were in earthquake-damaged areas, which were concentrated in a limited geographic area (Figure 4.1), and thus are not representative of Christchurch's complete population. Finally, compared to most cities around the world where redevelopment is ongoing, the redevelopment of Christchurch is a specific consequence of the 2010 – 2011 CES. This also suggests that the results may not be comparable in a generalised way, as many landowners redeveloping properties in this study are doing so out of necessity.

4.5 Conclusion

As a global phenomenon, redevelopment in cities is affecting the relationship between humans and their environment. This is especially evident when it comes to urban forest dynamics that can be influenced by landowners' attitudes towards landscape management. This study explored the relationship between resident attitudes and tree removal, retention, and planting in Christchurch, New Zealand, a dynamic city with substantial ongoing redevelopment.

In conjunction with previous research on the topic, the results suggest that some tree removal during redevelopment was a result of construction logistics. However, the questionnaire respondents in this study were highly conscious of the benefits of trees, with many choosing to retain trees on their properties during redevelopment and also to plant new trees on their redeveloped properties to maximise the ecosystem services trees provide. This suggests that major construction is a moment when residents' attitudes towards trees are not the primary factors in decisions to retain or remove trees.

The results show that residents from redeveloped properties were more likely to engage in tree removal and tree planting than residents from a property that was not redeveloped. Conversely, residents on non-redeveloped properties were more likely to retain their existing trees relative to residents on redeveloped properties. Overall, residents were most likely to remove trees if they were in conflict with redevelopment or, on non-redeveloped properties, if they perceived the tree to be in poor health. While ecosystem disservices (e.g. leaf litter, root damage to infrastructure) were cited as common reasons for tree removal, ecosystem services were presented as important reasons for both tree planting and tree retention. A significantly larger proportion of respondents from redeveloped properties noted that their reason for tree planting was because trees were aesthetically pleasing, highlighting the importance of trees in landscape design. Interestingly, two of the reasons given for retaining trees were the high cost of removal and the existence of government regulation, preventing their removal. This finding supports the importance of legislation or bylaws to provide incentives for tree retention and imposition of financial penalties for tree removal to limit tree removal.

Chapter 5

Conclusion

5.1 Summary of Main Findings

In Christchurch, New Zealand, thousands of residential dwellings were demolished and redeveloped between 2011 and 2015 as they, and the properties on which they were built, were severely damaged by the 2010 – 2011 Canterbury Earthquake Sequence (CES) (Christchurch City Council, 2015; Quigley et al., 2016). While a localised study has shown trees were negatively affected by property demolition in the Christchurch City Centre (Morgenroth et al., 2017), little is known about the wider topic of the effect of redevelopment on urban forest dynamics. Likewise, the causal factors of property-scale urban tree dynamics during redevelopment are not well understood. This is problematic as property-scale dynamics can have cumulative effects on broader urban forest dynamics. Urban forests play an important role in delivering ecosystem services and are, therefore, beneficial to human wellbeing in cities. As a consequence, it is critical to have a comprehensive understanding of how property redevelopment affects urban forest dynamics at a variety of spatial scales. Moreover, qualifying the contributions of morphological, socio-economic, and human dimensions on property-scale tree management will provide a better understanding of the reasons trees are removed, retained, and planted during property redevelopment. These outcomes will provide empirical proof to urban forest managers and policy makers and help develop informed urban forest policy to maximise urban forest outcomes.

5.1.1 City- and Meshblock-scale Tree Canopy Cover Change

Chapter 2 delineated tree canopy in Christchurch, in 2011 and 2015, by applying remote sensing analysis techniques to aerial imagery and LiDAR data. The Random Forest classifier produced greater than 95% classification accuracies for tree canopy class in both time periods. Subsequently, this research quantified and evaluated tree canopy cover change at the meshblock scale. The results show a relatively small magnitude of tree canopy cover loss from 10.8% to 10.3% between 2011 and 2015 over the study area, but a statistically significant change in tree canopy cover across all the meshblocks.

Meshblocks containing properties that underwent a complete redevelopment cycle experienced a greater magnitude of tree canopy cover loss than meshblocks without residential property redevelopment. Despite this, the density of redevelopment within meshblocks did not affect tree canopy cover loss.

This chapter highlighted three deficiencies, which were addressed in subsequent chapters. Namely, 1) tree canopy cover, as a response variable, was not appropriate to understand removal of individual trees; 2) large changes in tree cover within single properties did not necessarily result in significant tree canopy cover loss at the scale of the meshblock; 3) quantifying tree canopy cover loss failed to provide insight into reasons for tree removals during redevelopment.

5.1.2 Property-scale Individual Tree Dynamics

Chapter 3 presented the results of research on predictors of property-scale tree removal and retention. Initially, a mail-based questionnaire was delivered to two groups: 1) residential properties that had experienced a complete redevelopment cycle, and 2) residential properties that had not been redeveloped. This served the purpose of collecting resident and household data. 450 residential properties (321 redeveloped, 129 non-redeveloped) returned valid questionnaires and were identified as analysis subjects. Subsequently, by refining tree canopy classification results extracted from chapter 2, individual tree crowns were manually delineated within the 450 properties; this was done for both 2011 and 2015 and was based on aerial imagery and LiDAR data. The outcome of this individual tree mapping identified individual trees that had been removed or retained on properties during the analysis period. The results indicate that 2,422 trees were removed and 4,544 trees were retained between 2011 and 2015. Relatively small trees were more likely to be removed, while trees with large crowns were more likely to be retained. The tree removal rate on redeveloped properties (44.0%) was over three times greater than on non-redeveloped properties (13.5%) and the average canopy cover loss on redeveloped properties (52.2%) was significantly greater than on non-redeveloped properties (18.8%).

To explore the role of causal factors, Classification Trees were used to model individual tree dynamics (i.e. tree removal, tree retention) and candidate explanatory variables (i.e. resident and household, economic, land cover, and spatial variables). The results showed the model including land cover, spatial, and economic variables had the best predicting ability for individual tree dynamics and indicated that property redevelopment was the best predictor of tree removal. Other important factors that affected tree dynamics were property capital value in 2016, parcel area, and the distance between a tree crown boundary and the boundary of a redeveloped building or the property's driveway. Specifically, trees on redeveloped properties with capital values lower than NZ$1,060,000 or parcel areas less than 1,107 m^2 were more likely to be removed. In terms of the spatial determinants, trees were more likely to be removed due to close proximity to a redeveloped building (< 1.4 m) or a driveway (< 10 m) on a redeveloped property. Interestingly, this chapter found property-scale tree dynamics were insensitive to resident and household factors.

5.1.3 Resident Attitude and Actions towards Trees

Finally, Chapter 4 explored the relationship between resident attitudes and their tree management actions (i.e. tree removal, retention, and planting). Landowners from the 450 redeveloped and non-redeveloped residential properties were also asked, via mail questionnaire, to indicate their attitudes towards tree management. After excluding questionnaires that failed to meet validation criteria, 445 questionnaires were used for further analyses.

The results showed that respondents' tree management actions varied based on whether their property had been redeveloped. Specifically, respondents from redeveloped properties were more likely to engage in tree removal and tree planting than those from non-redeveloped properties, while existing trees were more likely to be retained by respondents from properties that were not redeveloped.

Generally, residents indicated ecosystem disservices (e.g. leaf litter, root damage to infrastructure) as common reasons for tree removal, while noting ecosystem services as important reasons for both tree planting and tree retention on their properties. However, many reasons for tree removal and tree planting were unevenly noted by residents from redeveloped properties versus non-redeveloped properties. Most tree removal occurred on redeveloped properties because they were in conflict with redevelopment, but occurred on non-redeveloped properties because of perceived poor tree health. Residents from redeveloped properties were more likely to plant trees as they are aesthetically pleasing or to replace trees removed during redevelopment.

5.2 Research Implications

The results of this research support previous research that has emphasised the negative effect of urban redevelopment on urban greenspace and forests (Brunner & Cozens, 2013; Dallimer et al., 2011; Jim, 1998). While previous studies have found tree canopy cover loss was a result of increased building density (e.g. Davies et al., 2008), this research did not find any correlation between tree canopy cover change and residential property redevelopment density, at the meshblock scale. This implies that the choice of geographic unit may affect the analytical sensitivities between response and explanatory variables. As tree management decisions are generally made at the scale of individual properties, applying a finer scale boundary (e.g. individual property) may yield different outcomes. Additionally, when exploring the effect of property redevelopment density on urban forest dynamics, this research employed tree canopy cover as the response variable because it is highly correlated with ecosystem services (McPherson et al., 2011) and is a typical metric used in urban forest policy documents (Ordóñez & Duinker, 2013). But, tree canopy cover is coarse and can not capture the diversity of individual trees (Morgenroth & Östberg, 2017). As such, applying other urban forest metrics (e.g. individual trees or stem density) may better monitor urban forest dynamics during property redevelopment.

This research also provided an opportunity to explore property-scale urban tree dynamics during property redevelopment. Beyond the dominant influence of whether redevelopment occurred, other land cover, economic, and spatial variables had better predicting performance of tree removal and retention than resident and household variables. This highlights that property-scale tree dynamics are affected more by built environment and economic factors than who the landowners are. These findings have implications for urban forest management. Governments may design specific legislation or policy to protect trees during property redevelopment. Though a guideline called "A guideline for tree and bush protection on development sites" exists in New Zealand (New Zealand Arboricultural Association, 2011), there is no legal authority forcing landowners and developers to be in accordance with it. This research provides the empirical support for developing future legislation or policy about urban forest management during redevelopment. Specifically, governments may regulate the necessity of replacing unavoidable tree removal, specify a minimum pervious:impervious surface ratio during redevelopment, or specify minimum distances between buildings and trees.

Many residents who participated in this research (i.e. landowners) were aware of ecosystem services provided by trees and thus retained existing trees and/or planted new trees. However, those residents who engaged in tree planting may have chosen inappropriate tree species due to limited knowledge about trees (Shackleton & Shackleton, 2016; Verbrugge et al., 2013), which could lead to potential tree removal in the future. To support effective species selection and tree planting on residential properties, urban foresters could provide opportunities for the public to learn about urban trees (e.g. a list of suitable tree species for garden and neighbourhoods (Wyse et al., 2015)). Meanwhile, as building contractors play a direct role in undertaking property redevelopment, it is important that they be educated on the ecosystem services urban trees provide and tree protection methods and thus to ensure the minimal negative effect of property redevelopment on in situ trees.

5.3 Limitations and Future Research

This research derived tree canopy from aerial imagery and LiDAR data. As such, it was dependent on accurate classification results. While the Random Forests classifier yielded high classification accuracies for tree cover (> 95%), the misclassifications may have affected tree canopy cover estimates and thus contributed to the relatively minor canopy cover loss between 2011 and 2015 over the study area.

The fixed elevation threshold used to distinguish tall from short objects during classification may have excluded some trees. As chapter 4 found many residents practiced tree planting after 2011; it is reasonable to assume many of those newly planted trees are likely to be short and thus were misclassified as non-tree objects. However, given that the elevation threshold was applied equally to

2011 and 2015 classifications, the underestimation of tree cover that would have resulted would apply equally to both time periods. Another image classification limitation was the lack of near-infrared band in the aerial imagery. Future research could apply the near-infrared band to calculate the Normalized Difference Vegetation Index (NDVI) to optimise classification results, which has been assessed as an important method to extract tree canopy in the context of urban area (Alonzo et al., 2014; Ke et al., 2015). Despite these shortcoming, the > 95% tree cover accuracy achieved suggests relatively minor improvements could be made by including a near-infrared band in imagery and altering the fixed elevation threshold.

This research identified properties that had been redeveloped based on a list of Code of Compliance Certificates (CoCC) that was issued by Christchurch City Council to approve a property's redevelopment. But, the CoCC did not include information about housing types of the redeveloped property (e.g. single-unit house or multi-unit apartment). As previous studies revealed urban forests respond differently to housing types (Lee et al., 2017; Nielsen & Jensen, 2015; Troy et al., 2007), future research could consider housing type as a causal factor to measure the effect of property redevelopment on urban forest dynamics.

Chapter 3 and 4 employed a mail questionnaire as a method of data collection, but the response rate was lower than many previous studies (e.g. Conway, 2016; Larson et al., 2010). This may have led to a respondent profile that was dissimilar to the rest of Christchurch's population, and thus, non-generalisable results. To encourage resident participation and increase response rate, future research should consider ethno-cultural diversity and thus distribute questionnaires in multiple languages. Besides this, future research also could adopt multi-contact or face-to-face invitations to conduct questionnaires, which has also been suggested as a useful way to increase response rate by empirical research (Dillman, 2000; Kirkpatrick et al., 2012).

Finally, unlike most cities around the world that experience a natural urban redevelopment cycle, Christchurch's redevelopment results specifically from the 2010 – 2011 CES. Most of properties in this research were concentrated in earthquake-damaged areas and were redeveloped out of necessity. As such, the effect of property redevelopment on urban forest dynamics in this research may not be comparable, in a generalised way, to redevelopment in other parts of New Zealand, or the wider world. Future research could differentiate the mechanism of property redevelopment (i.e. earthquake-related or not) and include further analysis of how urban forest's respond to urban redevelopment from a long-term perspective.

5.4 Conclusion

In summary, this research accurately delineated tree canopy in Christchurch by applying the Random Forest classifier to aerial imagery and LiDAR data in both 2011 and 2015. Estimated tree canopy covers were used to quantify changes in tree canopy cover in the five years of redevelopments that followed the earthquakes. This provided a foundation for subsequent analyses that evaluated the effect of property redevelopment on Christchurch's urban forest dynamics at a range of spatial scales and thus answered the research questions proposed in chapter 1.

Specifically, the research found that:

1. Property redevelopment has affected tree canopy cover change in Christchurch. At the meshblock scale, meshblocks that experienced property redevelopment were more likely to incur tree canopy cover loss, but the loss was not affected by the density of property redevelopment.

2. Property redevelopment also played the dominant role in affecting property-scale individual tree dynamics. Tree removal was more likely to occur on properties that had been redeveloped. On a redeveloped property, tree removal or retention was also related to the size of the property, the economic value of the property, and spatial factors (i.e. the distance between a tree crown boundary and the boundary of a redeveloped building or the property's driveway). In contrast, resident and household factors had less effect on property-scale individual tree dynamics during property redevelopment.

3. Resident attitudes and actions towards trees varied based on their property redevelopment status. Residents from properties that had been redeveloped were more likely to remove and/or plant trees, while residents from properties that were not redeveloped were more likely to retain existing trees. In terms of attitudes towards those tree management actions, residents from redeveloped properties were more likely to engage in tree removal because trees were in conflict with redevelopment, but also more likely to plant trees as they are aesthetically pleasing or to replace trees removed. In contrast, residents from non-redeveloped were more likely to remove trees as a consequence of perceived poor tree health or ecosystem disservices.

Clearly, urban redevelopment has affected Christchurch's urban forest dynamics. By having a comprehensive understanding how urban forests respond to property redevelopment, this research adds to the empirical proof that has suggested urban redevelopment as a causal factor of the uneven distribution of urban forests from a spatio-temporal perspective. Meanwhile, this research also complements the existing literature showing the effect of a complete property redevelopment cycle on property-scale tree management.

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Appendices

Appendix A. Feature inclusion for object-based image analysis

Category	Feature	Reference source[1]				
		Carleer and Wolff (2008)	Du, Zhang, and Zhang (2015)	Pu et al. (2011)	Ma et al. (2017)	O'Neil-Dunne, MacFaden, and Royar (2014)
Spectral features	Mean R, G, B					
	Standard deviation R, G, B					
	Brightness					
	Maximum difference					
	Ratio of R, G, B					
Textural features	GLCM Homogeneity					
	GLCM Contrast					
	GLCM Dissimilarity					
	GLCM Entropy					
	GLCM Ang. 2nd Moment					
	GLCM Mean					
	GLCM Correlation					
Geometry features	Length/Width					
	Asymmetry					
	Border index					
	Compactness					
	Density					
	Elliptic fit					
	Radius of largest enclosed ellipse					
	Radius of smallest enclosed ellipse					
	Rectangular fit					
	Roundness					
	Shape index					
	Area (excluding inner polygons)					
	Area (including inner polygons)					
	Compactness (polygon)					
	Number of edges (polygon)					
LiDAR derived features	Mean nDSM					
	Standard deviation nDSM					
	Mean Slope					
Additional features	VARI – Visible Atmospheric Resistant Index	Gitelson, Kaufman, Stark, and Rundquist (2002)				
	TGI – Triangular Greenness Index	Hunt et al. (2013)				

1 – Grey represents the selected feature is derived from the corresponding reference.

Appendix B. Tree canopy cover change including plantation forests

The percentage of tree canopy cover over the study area was 13.40% (tree canopy area = 26.4 km2) in 2011 but decreased to 11.83% (tree canopy area = 23.3 km^2) in 2015. The total tree canopy area decreased by 3.1 km^2 between 2011 and 2015. Tree canopy cover (TCC) loss occurred in 1,107 (55%) meshblocks, while 903 (45%) meshblocks gained TCC (Figure B1). The results of paired samples t-test show that there was a significant difference (p < 0.001, t(2011) = 12.13) between mean TCC in 2011 (M = 11.66%, $S.E.$ = 0.18%) and mean TCC in 2015 (M = 10.83%, $S.E.$ = 0.15%).

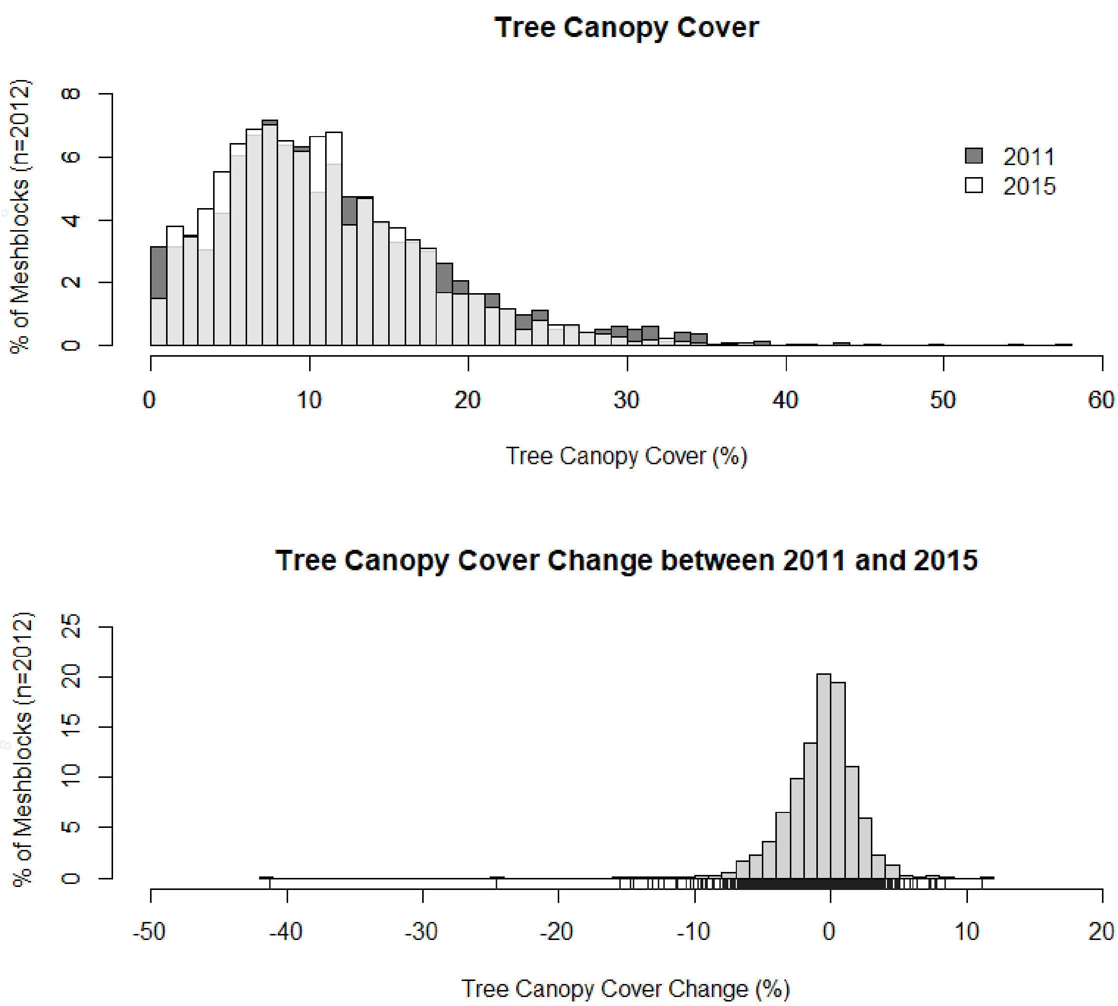

Figure B1 – Tree canopy cover change (including plantation forests) between 2011 and 2015.

Appendix C. Questionnaire Sample

UNDERSTANDING TREE COVER CHANGE IN CHRISTCHURCH

27 January, 2017
XX Clifford Avenue
FENDALTON
CHRISTCHURCH 8014

Participant:
The ideal participant is the person in the household that is the primary decision maker.

Guide for how to answer

- *mark your answer like this:* ☑
- *if you make a mistake, do this:* ☐
- *print answers in CAPITAL LETTERS like this:*

S	H	O	R	T	L	A	N	D		S	T	R	E

Q1. Do you currently live at *XX Clifford Avenue*?

☐ Yes
☐ No

Q2. Did you live at *XX Clifford Avenue* on 22 February 2011?

☐ Yes
☐ No

Q3. Did you live at *XX Clifford Avenue* on 4 September 2010?

☐ Yes
☐ No

Q4. How many years have you lived at *XX Clifford Avenue*?

☐ Never or ☐☐ Number of years

Q5. In the next 12 months, do you expect to:

☐ remain at *XX Clifford Avenue*
☐ shift to another address
☐ I don't live at *XX Clifford Avenue*

Q6. Has your property at *XX Clifford Avenue* been redeveloped since 4 September 2010?

☐ Yes
☐ No

Q7. Mark as many spaces as you need to explain why trees have been REMOVED at *XX Clifford Avenue* since 4 September 2010.

Guide Notes:
Removing trees means that trees that were on the property prior to 4 September 2010 are no longer on the property.

☐ No trees have been removed
☐ Trees were in the way of demolition or construction vehicles or equipment, so had to be removed
☐ Trees were removed to make space for the new development
☐ Trees obscure my view
☐ Trees shade my house
☐ Trees shade my garden
☐ Trees drop messy leaves, flowers, fruit or branches
☐ Trees attract unwanted animals or insects
☐ Trees use too much water
☐ Tree roots damage drains, foundation or hard landscaping
☐ Trees interfere with underground or aboveground services
☐ Trees promote criminal activities
☐ Trees require too much maintenance
☐ Trees were exotic or invasive species
☐ Trees were damaged, diseased or dead
☐ Trees cause allergies or health problems
☐ Trees reduce property value
☐ Trees increase heating or cooling costs
☐ Other. Please state:

Q8. Mark as many spaces as you need to explain why trees were RETAINED at *XX Clifford Avenue* since 4 September 2010.

Guide Notes:
Retaining trees means that trees that were on the property prior to 4 September 2010 remain on the property now.

☐ No trees were retained
☐ Trees are aesthetically pleasing
☐ Trees improve air quality
☐ Trees stabilize the soil
☐ Trees provide shade
☐ Trees provide privacy
☐ Trees provide fruit or nuts
☐ Trees reduce noise
☐ Trees celebrate a person or pet
☐ Trees provide recreation potential
☐ Trees increase property value
☐ Trees reduce heating or cooling costs
☐ Trees are culturally important
☐ Trees provide habitat for birds
☐ Trees provide habitat for bees
☐ High costs for removal
☐ Government regulation prevents tree removal
☐ Have not yet had time to remove
☐ Trees are native species
☐ Other. Please state:

Q9. Mark as many spaces as you need to show all the reasons why trees have been PLANTED at *XX Clifford Avenue* since 4 September 2010.

Guide Notes:
Planting trees means that new trees that were not on the property prior to 4 September 2010 have been planted.

☐ No trees have been planted
☐ Trees are aesthetically pleasing
☐ Trees improve air quality
☐ Trees stabilize the soil
☐ Trees provide shade
☐ Trees provide privacy
☐ Trees provide fruit or nuts
☐ Trees reduce noise
☐ Trees celebrate a person or pet
☐ Trees provide recreation potential
☐ Trees increase property value
☐ Trees reduce heating or cooling costs
☐ Trees are culturally important
☐ Trees provide habitat for birds
☐ Trees provide habitat for bees
☐ To replace the tree(s) removed
☐ Other. Please state:

Q10. How many trees have been:

Removed ☐☐ Number of trees | Retained ☐☐ Number of trees | Planted ☐☐ Number of trees

at *XX Clifford Avenue* since 4 September 2010?

Q11. Are you?

☐ male
☐ female

Q12. When were you born?

day (eg 30) ☐☐ month (eg 05) ☐☐ year you were born (eg 1956) ☐☐☐☐

Q13. Which ethnic group do you belong to?

- *Mark the space or spaces which apply to you.*

☐ New Zealand European
☐ Māori
☐ Samoan
☐ Cook Islands Māori
☐ Tongan
☐ Niuean
☐ Chinese
☐ Indian
☐ Other such as DUTCH, JAPANESE, TOKELAUAN. Please state:

Guide Notes:
An ethnic group is made up of people who have some or all of the following:

- a shared culture, such as traditions or ways of doing things, customs, beliefs or language
- a common ancestry or history
- a similar geographic, tribal or clan origin.

Examples of ethnic groups are: Māori, Samoan, Chinese New Zealander, Kiribati, Greek, Afrikaner, Eritrean, Kurd, Iraqi, Assyrian and Malay.

Q14. What is your religion?

☐ No religion
☐ Christian → Which of these, if any, are you?
  ☐ Anglican
  ☐ Catholic
  ☐ Presbyterian
  ☐ Methodist
  ☐ Rātana
  ☐ Ringatū
  ☐ Other. Print what it is:
☐ Buddhist
☐ Hindu
☐ Muslim
☐ Jewish
☐ Other religion. Print what it is:

☐ Or object to answering this question

Q15. What is your highest secondary school qualification?

☐ None
☐ NZ School Certificate in one or more subjects *or* National Certificate level 1 *or* NCEA level 1
☐ NZ Sixth Form Certificate in one or more subjects *or* National Certificate level 2 *or* NZ UE before 1986 in one or more subjects *or* NCEA level 2
☐ NZ Higher School Certificate *or* Higher Leaving Certificate *or* NZ University Bursary / Scholarship *or* National Certificate level 3 *or* NCEA level 3 *or* NZ Scholarship
☐ Other secondary school qualification **gained in NZ**. Print what it is: →
☐ Other secondary school qualification **gained overseas**

Q16. Apart from secondary school qualifications, have you completed another qualification?

- *DON'T count qualifications that take less than 3 months of full-time study to get.*

☐ Yes ⟶ go to **Q17**
☐ No ⟶ go to **Q18**

Q17. Print your highest qualification, and the main subject, for example:

qualification: *TRADE CERTIFICATE*
subject: *ELECTRICAL ENGINEERING*

- **qualification** (and level, if applicable)
- **subject**

Q18. From all sources of income, what was the total income

- *that all household members who are over 16 years of age got*
- *before tax or anything was taken out of it*
- *in the 12 months that ended on 31 December 2016*

☐ Loss
☐ Zero income
☐ $1-$5,000
☐ $5,001-$10,000
☐ $10,001-$15,000
☐ $15,001-$20,000
☐ $20,001-$25,000
☐ $25,001-$30,000
☐ $30,001-$35,000
☐ $35,001-$40,000
☐ $40,001-$50,000
☐ $50,001-$60,000
☐ $60,001-$70,000
☐ $70,001-$100,000
☐ $100,001-$150,000
☐ $150,001 or more

Guide Notes:

- Income includes: wages, salary, commissions, or bonuses paid by your employer; self-employment or bonuses that you own or work in; interest, dividends, rent, or other investments; regular payments from ACC or a private work accident insurer; New Zealand superannuation or Veteran's Pension; other superannuation, pensions or annuities; unemployment benefit; sickness benefit; domestic purposes benefit; invalid's benefit; student allowance; other government benefits, government income support payments, war pension, or paid parental leave.
- Count any payments that are taken out of your income **before** you get it, such as repayments of student loans, union fees, fines or child support.
- DON'T count loans (including student loans), inheritances, sale of household or business assets, lottery wins, matrimonial/civil union/de facto property settlements or one-off lump sum payments.

*If you know your weekly or fortnightly income **after tax**, use this table to work out your annual income **before tax**.*

Annual income (before tax)

After tax weekly income $	After tax fortnightly income $	Before tax annual income $
up to 86	up to 172	1 – 5,000
87 – 172	173 – 343	5,001 – 10,000
173 – 256	344 – 512	10,001 – 15,000
257 – 335	513 – 671	15,001 – 20,000
336 – 414	672 – 829	20,001 – 25,000
415 – 493	830 – 987	25,001 – 30,000
494 – 573	988 – 1,145	30,001 – 35,000
574 – 652	1,146 – 1,303	35,001 – 40,000
653 – 805	1,304 – 1,610	40,001 – 50,000
806 – 939	1,611 – 1,879	50,001 – 60,000
940 – 1,074	1,880 – 2,147	60,001 – 70,000
1,075 – 1,459	2,148 – 2,918	70,001 – 100,000
1,460 – 2,102	2,919 – 4,203	100,001 – 150,000
2,103+	4,204+	150,001+

Appendix D. A residential property was identified as a redeveloped property after visual comparison between 2011 and 2015/16 aerial photographs.